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AN ECONOMIC EVALUATION

By

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The errors still remaining are, of course, fully our responsibility. We welcome comments and suggestions for their elimination and for improvement of this study.

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June 30, 1976
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ABSTRACT

The economic analysis concentrates on what is known as "phosphate rock." This is ore which contains phosphorus but has no definitive chemical composition. The nature and quality of phosphate rock vary considerably, but some degree of comparability can be achieved by classifying the rock according to its percentage content of bone phosphate of lime (BPL) or phosphorus pentoxide (P_2O_5).

Reserve or resource statistics are generally inadequate. Most often one must settle for what is called "identified reserves." These say nothing about grade, quality, or the extent to which the ore can be mined profitably at prevailing market conditions and with current technology.

Assuming a reasonably low cost of production, offshore phosphorite producers are likely to find markets in Japan, South Korea, Taiwan, Philippines, and the western United States and Canada most attractive. Phosphate rock is bulky and has a fairly low monetary value per unit of commodity as compared to many other minerals. This holds true, despite recent price hikes from less than $10 to more than $40 per ton, depending on BPL classification. Transportation costs, therefore, play a significant role in determining how successful offshore phosphate rock will be in penetrating these markets. The availability of return cargo is a major factor in determining transportation costs.

The report outlines and presents capital and operating costs for two alternative dredging technologies, employing, respectively, an hydraulic suction dredge and an innovative jet lift dredge. Alternative arrangements for transportation onshore, unloading and beneficiation are evaluated.

Appropriate beneficiation methods are discussed in relation to the available information on mineral and chemical analyses of rock samples from the eight deposits under consideration.

On the basis of a given maximum attainable price for the phosphate rock, internal rates of return are calculated for each technological combination and for each of the two rates of production that are analyzed. Under the conditions assumed, the most proven technology does not appear to yield attractive rates of return, while those of the second technology are considerably higher. A crucial factor which must be considered in these evaluations is that of risk and how it should be accounted for. A model of risk analysis is developed and the sensitivity of the internal rates of return are evaluated also with respect to an alternative maximum attainable price of phosphate rock, alternative capital investment requirements and resource costs. A royalty versus bonus bidding leasing arrangement is discussed, and examples are given of how a royalty resource charge affects the internal rates of return.

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1. SOCIOECONOMIC CONSIDERATIONS

1.1 Introduction

In the economic evaluation of southern California phosphorites this study will take phosphate rock as the most appropriate basis of analysis. Even though the element phosphorus is what one is basically interested in, the latter is " . . . never found in a free or uncombined state because of its great affinity for oxygen . . . " (1) The term "phosphate rock," however, is generally used for any of the ores which contain phosphorus but " . . . it does not have a definite chemical composition and contains phosphorus minerals generally in the apatite group." (2) (3) This lack of specificity makes economic analysis more difficult. Instead of dealing with a homogeneous product and a correspondingly well-defined price, one has to consider a range of products and a range of prices.

The use of the terms bone phosphate of lime (BPL), tricalcium phosphate, and phosphorus pentoxide (P_2O_5), however, simplifies the economic problem considerably. They can be used interchangeably and basically serve as a "common denominator" of phosphate rock, bringing all different phosphate rocks to a common basis of phosphorus content. (4)

As is true with most minerals, this terminology does not solve the problem of heterogeneity of rock products. The great variety in the chemical and mineral composition of phosphate rocks is well known, and will be considered later in this report.

The heterogeneity of phosphate rock--in terms of phosphorus content and mineral and chemical composition as well as the numerous derivatives from the rock--tends to complicate the statistics that must be dealt with. The most logical analytical procedure would be to convert all products to

P_2O_5 and quote statistics in terms of P_2O_5. However, this is not always done; furthermore, when looking at the section on prices in Chapter 2, statistics based on P_2O_5 content will not be found equally useful. One is forced to utilize a mixture of statistics related to terms of P_2O_5, various grades and qualities of rock, all covered under the common term "phosphate rock," and numerous derivative products like fertilizers which are somewhat more specific and homogeneous. It is to be hoped that this lack of a uniform statistical base, while not distracting the reader from the more substantive issues, may grant him some appreciation for the statistical complexities characterizing this industry.

1.2 General Supply Considerations

1.2.1 Reserves and Reserve Statistics

The statistics on U.S. and world reserves of phosphates in Tables 1 and 2 clearly show that one is not dealing with a scarce resource. The tables are of most interest for the picture they give of relative reserves for countries and regions. Even this information is of limited value, however, since little is said about relative quality, grade or cost of recovery. In the final analysis, the missing information is indispensable. It will determine which of the existing reserves will be exploited and when. There are plentiful reserves of onshore phosphates and one might thus erroneously disregard offshore phosphate deposits as having little economic interest. The specifics required for any such conclusions, however, must include deposit quality, average grade as well as variability in grade, average

TABLE 1. WORLD PHOSPHATE RESERVES AND RESOURCES

Millions of Short Tons, Identified*

Country	Gross Weight	P_2O_5
United States	12,840	3,850
Latin America	810	245
Africa	29,585	8,875
West Asia	1,100	330
Asia (other areas)	3,370	1,430
Australia	1,685	505
Pacific Islands	50	15
TOTAL	49,440	15,250

*Identified: Specific identified mineral deposits that may or may not be evaluated as to extent and grade, and from which contained minerals may or may not be profitably recovered with existing technology and economic pattern.

Source: Blue, Thomas A., and Thomas F. Torries, Phosphate Rock, Stanford Research Institute, December, 1975; pp. 770.0008A-760.0008H. See footnote (7).

TABLE 2. U.S. PHOSPHATE RESERVES AND RESOURCES

Millions of Short Tons, Identified (See Table 1)

State(s)	Gross Weight
Florida	2,645
South, Coastal Georgia	1,200
North Carolina	2,205
Tennessee, Kentucky, Alabama	90
Idaho, Montana, Wyoming, Utah	6,615
All Others	85
TOTAL	12,840

Source: Blue and Torries, *op. cit.*, see footnote (7); p. 760.0003A.

value at point of sale, and information on the cost of recovery and processing. These aspects, and others, will be dealt with in this report.

One difficulty encountered in the study of phosphate rock is the absence of statistics that distinguish between reserves and resources. Here the term "reserves" would refer to known recoverable supplies that can be mined and refined at or near prevailing market prices using current technologies. The term "resources," on the other hand, usually designates supplies that cannot be produced at or near current technological and economic conditions. (5)

These two terms could be modified by the addition of those that make the classification even finer with respect to feasibility of economic recovery and the degree to which the deposits are known to exist.

One possible breakdown uses the terms "proved, probable, possible (all three of which occur in identified deposits) and undiscovered to suggest decreasing degrees of certainty concerning reserves and resources. Relative costs are suggested by the terms recoverable, paramarginal and submarginal." (6)

Resource and reserve data utilizing the distinctions described above are not available for phosphorus or phosphate rock. Since the well-documented Phosphate Rock report by Stanford Research Institute settles for "Identified Reserves," any better classification probably does not exist. The term is defined by SRI as " . . . specific identified mineral deposits that may or may not be evaluated as to extent and grade, and from which contained minerals may or may not be profitably recoverable with existing technology and economic pattern." (7, underlining is ours) This terminology says nothing about operating feasibility and therefore tells us very little about supplies that may be forthcoming at various times under various economic conditions.

Some more well-defined statistics have been found but these are deficient in other respects. The Institute of Ecology (TIE) has calculated "known (economic) deposits, adjusted for mining and refinery losses, of 3.14 billion tons of P." (8) However, in a later edition of its report the amount was changed to 20 billion tons in keeping with the U.S. Bureau of Mines estimates of known and potential reserves. This figure is apparently also accepted by Emigh, an acknowledged authority on phosphate supplies and former Director of Mining for the Monsanto Industrial Chemicals Company.

Such general figures are not of much use, however, since they say nothing about the grade or other characteristics of the deposit, nor about its location relative to transportation facilities, markets, etc. One must conclude that available data do not justify precise statements about phosphate reserves. More specifically, the absolute size of these statistics should not lead to the conclusion that the new, smaller deposits are of no value. In fact, with cost and revenue estimates, the more general statistics can be upgraded and given more meaning in terms of economic values.

1.2.2 Production and Trade

The world production of phosphate rock is dominated by the United States, the Soviet Union, and Morocco. In 1973, these countries produced 42.1, 23.4, and 18.3 million tons, respectively, or about 78 per cent of world production. (9) Table 3 shows both the actual production by country and the percentage share of the world production.

Other major producers are Tunisia, The People's Republic of China, Togo, Nauru, Senegal, Christmas Island, Israel, and Jordan.

The export markets are also dominated by the U.S., U.S.S.R., and Morocco, which provided 28.8, 15.3, and 28.2 per cent, respectively, of world exports of about 39 million long tons in 1970. (10) In Tables 4 through 8 a detailed account is presented of world trade in phosphate rock. The export statistics are given for the U.S., U.S.S.R., Morocco, a group of African and Middle Eastern countries, and finally, in Table 8, a group of "Pacific Basin" countries. Close attention will be paid to the "Pacific Basin" in the following chapters.

TABLE 3. WORLD PRODUCTION OF PHOSPHATE ROCK

Thousands of Short Tons, Gross Weight

Year	U.S.A.	U.S.S.R.	Morocco	World
1940	4,556 (N.A.)	2,866 (N.A.)	757 (N.A.)	N.A.
1950	12,448 (N.A.)	3,365 (N.A.)	4,268 (N.A.)	N.A.
1960	19,618 (43.6)	7,717 (17.1)	8,274 (18.4)	45,018
1965	29,482 (42.4)	14,850 (21.3)	10,810 (15.5)	69,585
1970	38,739 (43.3)	19,600 (21.9)	12,565 (14.05)	89,462
1975p*	48,000 (40.7)	25,000 (21.1)	14,500 (12.3)	117,875

*p: preliminary.

Source: Blue and Torries, op. cit., pp. 770.0008F-760.0008H.

A last piece of general information which should be provided in this section on general supply is concerned with the grades of phosphate rock sold or used in the U.S. Table 9 shows several interesting features with respect to grades, indicating the fastest rates of growth in demand. These statistics will prove even more valuable when related to statistics in Chapter 2 which show time-series data on consumption by major products. Also, these developments will make relative prices and their changes more understandable as these are discussed and evaluated in Chapter 2.

A detailed description of the world export market is provided in Tables 4-8.

TABLE 4. U.S. EXPORTS OF PHOSPHATE ROCK, 1000 TONS

Region of Destination	1970	1971	1972	1973	1974
1. North America	3,139	3,579	3,807	4,550	4,865
2. Central & South America	601	763	948	900	918
3. Western Europe	4,494	4,694	4,912	4,522	4,113
4. Eastern Europe	0	0	421	272	333
5. Asia	3,455	3,563	3,871	3,686	3,970
6. Oceania	13	0	0	0	0
7. Other	36	88	33	2	9
TOTAL	11,738	12,687	13,992	13,932	14,208

Source: Taken, or derived, from Blue and Torries, *op. cit.*, pp. 760.0006Q,R and 760.0008S-760.0009V. See footnote (7).

TABLE 5. U.S.S.R. EXPORTS OF PHOSPHATE ROCK, 1000 TONS

Region of Destination	1970	1971	1972	1973	1974
1. Western Europe	2,156	2,375	2,380	2,813	2,723
2. Eastern Europe	4,063	4,316	4,593	4,463	4,470
3. Asia	283	276	143	220	992
TOTAL	6,502	6,967	7,116	7,496	8,185

Source: Taken, or derived, from Blue and Torries, *op. cit.*, pp. 760.0006Q,R and 760.0008S-760.0009V.

TABLE 6. MOROCCAN EXPORTS OF PHOSPHATE ROCK, 1000 TONS

Region of Destination	1970	1971	1972	1973	1974
1. North America	0	281	365	463	733
2. Central & South America	90	71	122	305	678
3. Western Europe	8,953	9,037	10,170	11,272	12,693
4. Eastern Europe	1,885	2,287	2,792	3,427	5,043
5. Africa	0	0	0	29	0
6. Asia	1,479	1,372	1,467	2,188	1,398
7. Oceania	64	53	32	55	57
TOTAL	12,471	13,101	14,948	17,739	20,602

Source: Taken, or derived, from Blue and Torries, op. cit., pp. 760.0006Q,R and 760.0008S-760.0009V.

TABLE 7. EXPORTS OF ALGERIA, SENEGAL, TOGO, FORMER SPANISH SAHARA, TUNISIA, ISRAEL, AND JORDAN, 1000 TONS

Region of Destination	1970	1971	1972	1973	1974
1. North America	67	28	6	31	130
2. South & Central America	79	127	196	222	418
3. Western Europe	4,556	4,607	5,309	6,116	8,237
4. Eastern Europe	1,852	1,788	1,390	1,251	1,461
5. Africa	1	2	42	57	94
6. Asia	739	928	1,232	1,583	2,497
TOTAL	7,294	7,480	8,175	9,260	12,837

Source: Taken, or derived, from Blue and Torries, op. cit., pp. 760.0006Q,R and 760.0008S-760.0009V.

TABLE 8. EXPORTS OF AUSTRALIA, CHRISTMAS ISLAND, AND NAURU, 1000 TONS

Region of Destination	1970	1971	1972	1973	1974
1. North America	0	0	0	0	25
2. Central & South America	0	0	0	0	0
3. Western Europe	0	0	0	0	0
4. Eastern Europe	0	0	0	0	0
5. Africa	0	0	0	0	0
6. Asia	0	218	108	203	437
7. Oceania	1,108	2,830	2,225	3,700	3,751
TOTAL	1,108	3,048	2,333	3,903	4,213

Source: Taken, or derived, from Blue and Torries, *op. cit.*, pp. 760.0006Q,R and 760.0008S-760.0009V.

TABLE 9. TOTAL U.S. PHOSPHATE ROCK - SOLD OR USED BY PRODUCERS BY GRADE THOUSANDS OF SHORT TONS

Year	<60%BPL*	60-66%	66-70%	70-72%	72-74%	>74%
1970	4,731	3,206	12,974	4,090	9,220	4,544
1971	4,500	2,292	15,297	5,582	8,743	3,885
1972	4,164	2,752	17,722	4,507	9,678	4,925
1973	3,299	3,566	16,955	5,552	6,813	4,292
1974p**	2,712	10,074	20,343	5,909	5,618	3,778

*<60%BPL: 1 per cent B.P.L. is equivalent to 0.458 per cent P_2O_5.

**p: preliminary.

Source: Blue and Torries, *op. cit.*, p. 760.0004Z.

1.3 Mining and Beneficiation of Phosphate Rock

While both open pit and underground forms of mining are practiced in producing phosphate ores, the former is predominant. This mode of operation prevails both in Florida and in Morocco where the overburden is stripped and ore is mined by large, electric dragline excavators equipped with huge buckets.

Most of the ore in the United States must be treated or upgraded before it can be utilized as intermediate products or sold in phosphate rock markets. In this upgrading process washers, classifiers, sizing screens, flotation equipment, cones, and spirals of various sorts are used. (11)

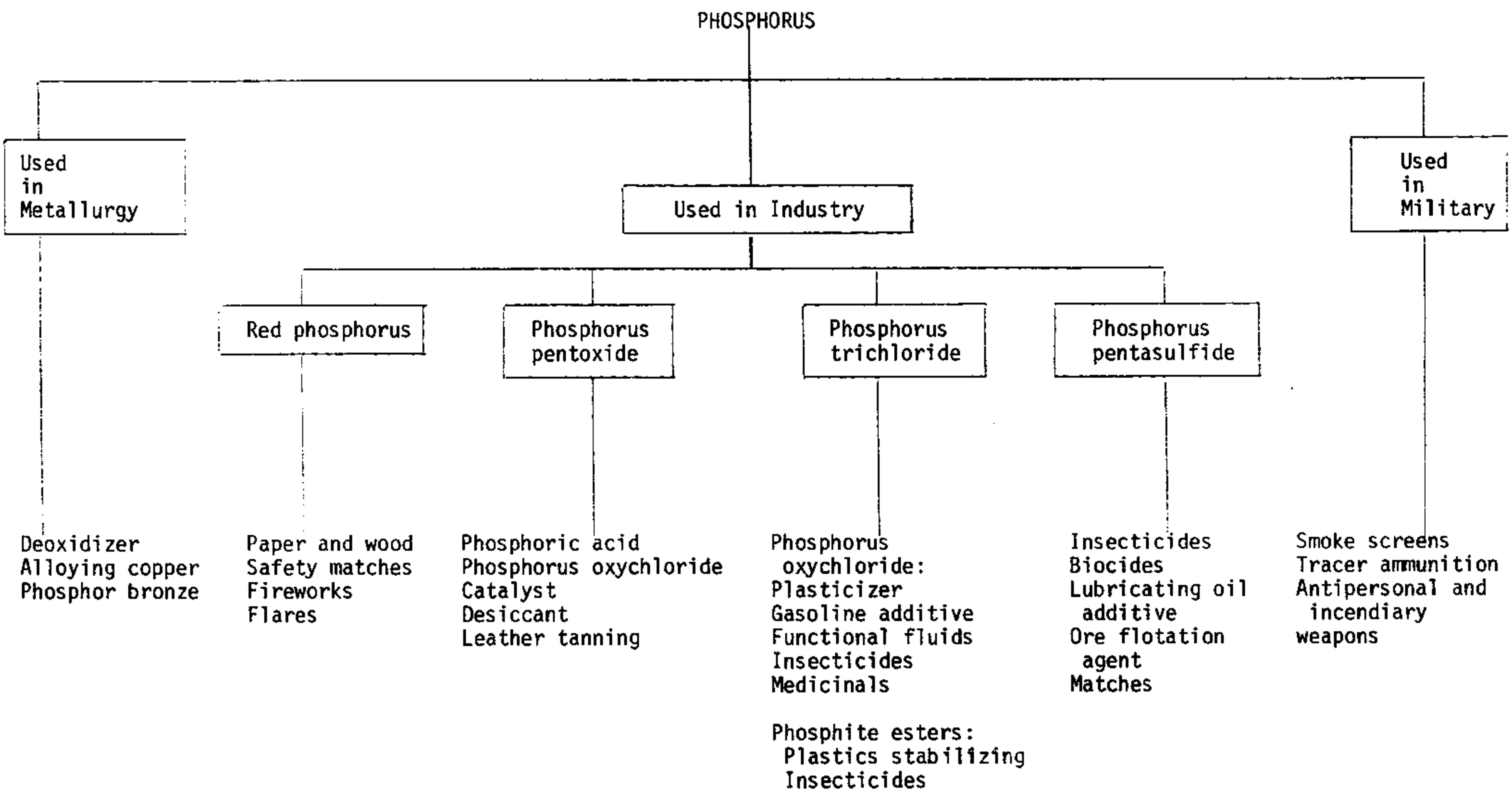
For an understanding of potential offshore phosphorite mining there are several characteristics of onshore mining that should be considered. One obvious problem peculiar to onshore mining is the large overburden which must be excavated prior to mining of phosphorite ore. In contrast, offshore phosphorites of current interest lie on the ocean floor. In addition, the onshore overburden problem plus the mining operation require eventual reclamation for some of these onshore mined areas. (12) The public demand for land reclamation should be considered in onshore cost evaluation. The noise, dust, and road/rail transportation which are part of onshore mining activity also are cost items of relatively great importance in onshore mining. Consider further the slime ponds in Florida, where phosphorus-containing slimes from washing and flotation processing are placed to settle the phosphorus, leading to occasional overflows into the surrounding countryside and waterways. It must be clear, then, that alternative offshore mining methods have some significant environmental cost advantages which may partially or fully offset the cost disadvantages. The mere fact that existing onshore operations may be profitable to the companies involved is not always sufficient justification. The private rate of return on an investment is only sufficient consideration when no significant externalities exist. Whether positive or negative, externalities should be accounted for in the economic evaluation and only by doing this will one find the actual social rate of return from these types of projects. (13)

1.4 End Products of Phosphate Rock

According to the Stanford Research Institute report,". . . at least 90% of the world's annual phosphate rock supply is typically converted into phosphorus and phosphoric acid intermediates which are further processed into the various end chemicals consumed in agriculture and industry. The primary market for these phosphate rock derivatives is agriculture; it is estimated that at least 85% of world supply is annually consumed in fertilizers, with an additional 4-6% used in livestock and poultry feeds and in pesticides." (14)

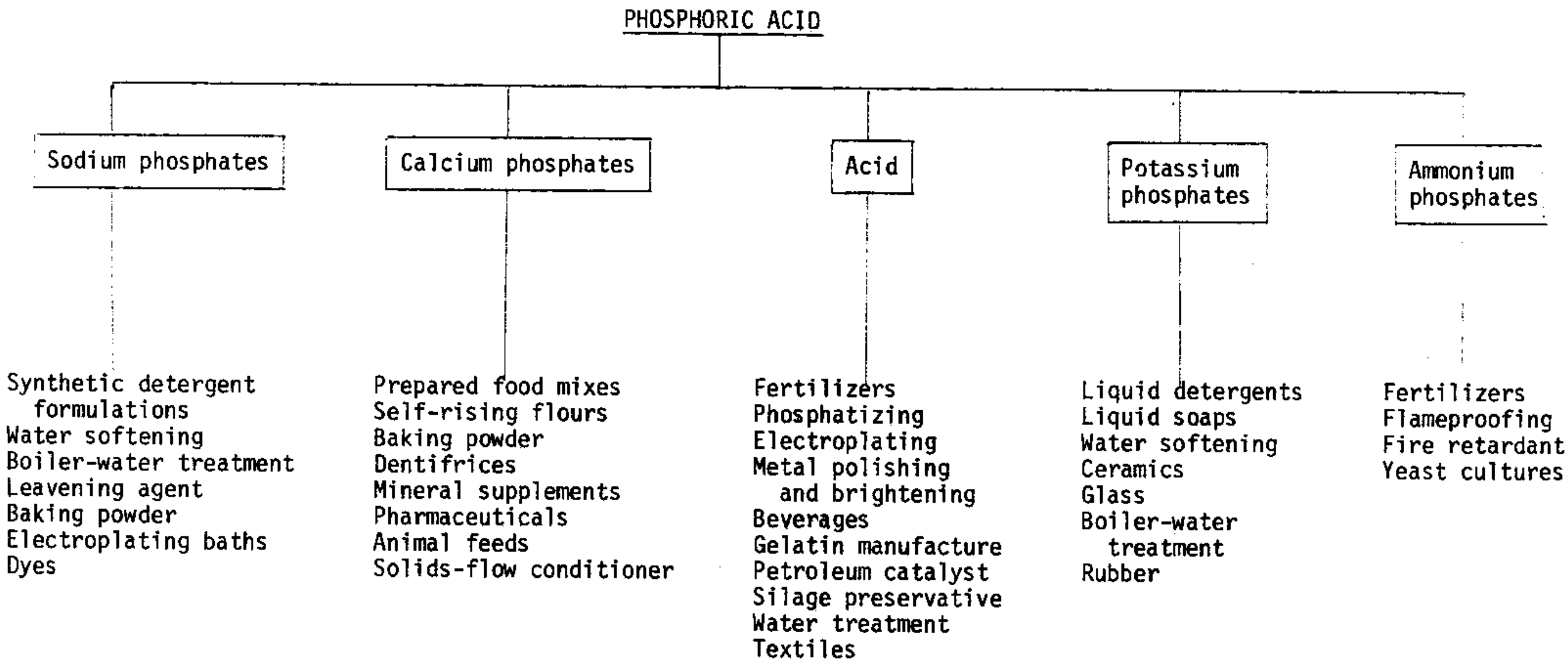
In order to relate phosphate rock to final products in industry and agriculture, one can examine the market for the two intermediate products--phosphorus and phosphoric acid. This is done in Figs. 1 and 2. Figure 3 presents a flow diagram of fertilizer products manufactured from phosphate rock. Also, to relate end uses and the principal forms in which rock are used to the grades of BPL of the phosphate rock, Fig. 4 is provided.

FIG. 1. END USES OF PHOSPHORUS



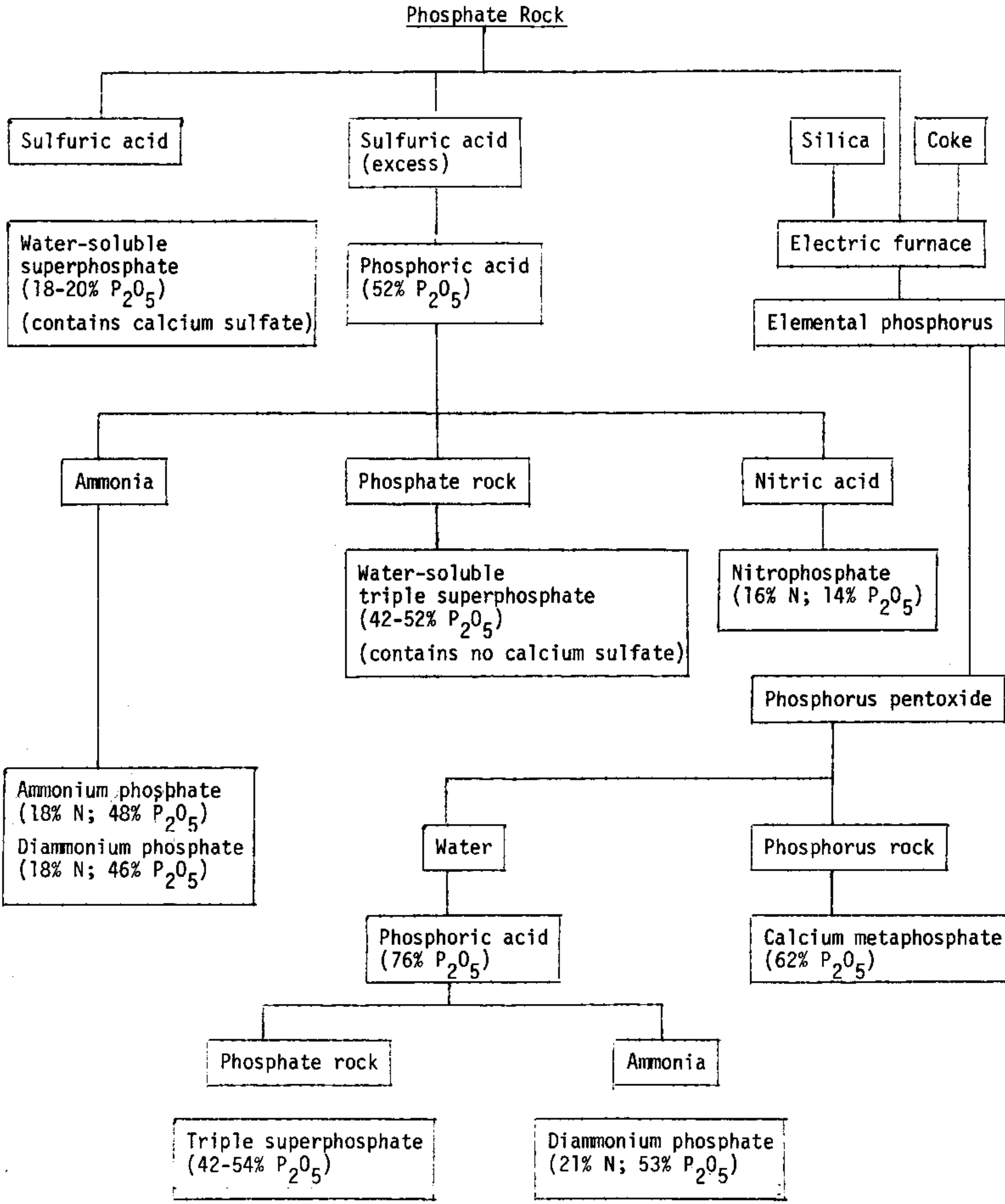
Source: Hee, Olman, A Statistical Analysis of U.S. Demand for Phosphate Rock, Potash and Nitrogen, Bureau of Mines, U.S. Department of the Interior, Information Circular 8418, 1969.

FIG. 2. END USES OF PHOSPHORIC ACID



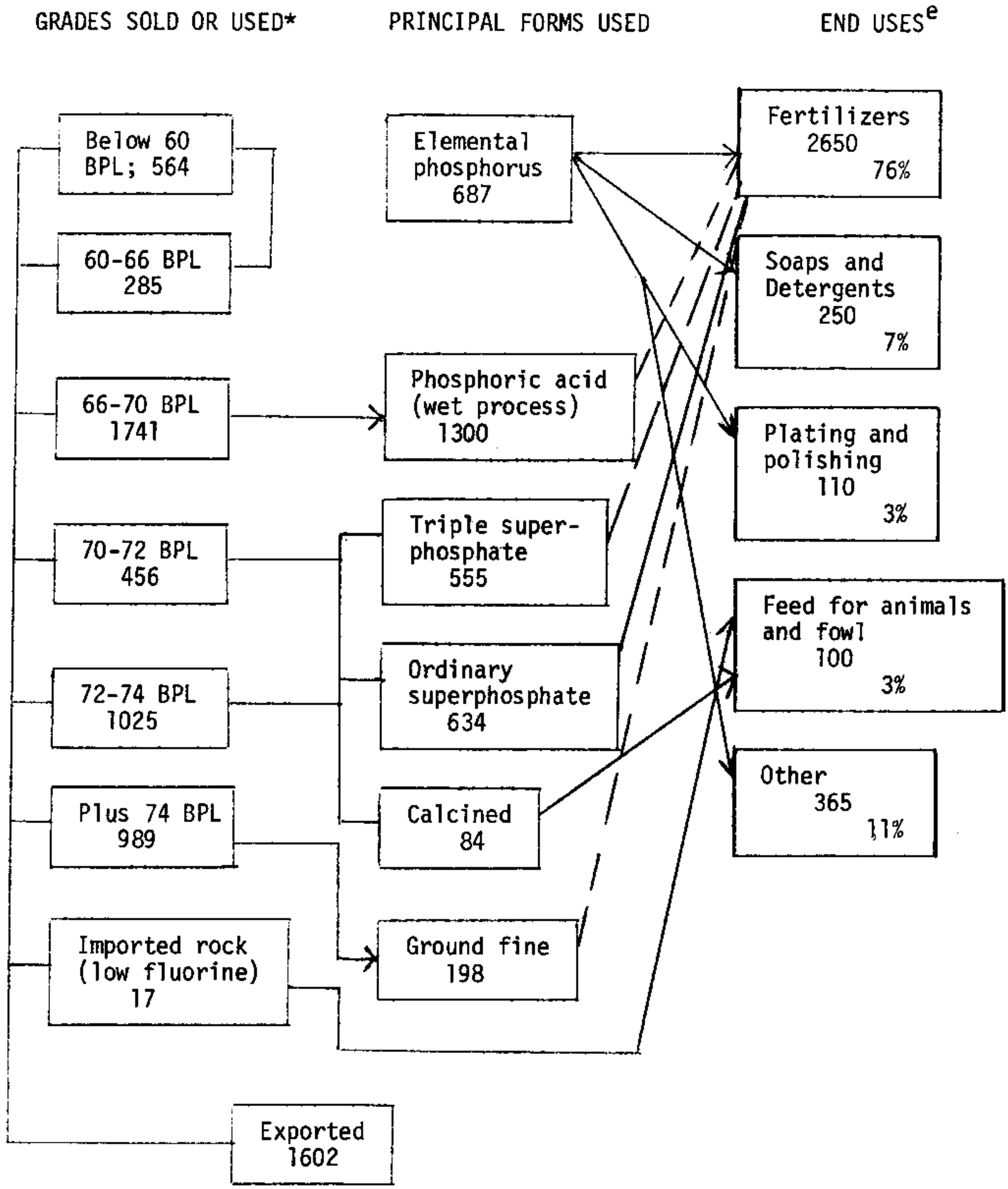
Source: Hee, loc. cit.

FIG. 3. PHOSPHATE FERTILIZERS FROM PHOSPHATE ROCK



Source: Hee, *loc. cit.*

FIG. 4. RELATIONSHIPS BETWEEN END USE AND GRADE OF PHOSPHATE ROCK



* Unit: Thousand short tons P content.
BPL: Bone Phosphate of Lime. 1 per cent BPL is equivalent to 0.458 per cent P_2O_5.
e: estimated.

Source: Lewis, Richard W., "Mineral Facts and Problems," Bulletin 650, Bureau of Mines, U.S. Department of the Interior, 1970, p. 1147.

References and Footnotes to Chapter 1

(1) Lewis, Richard W., Mineral Facts and Problems, Bulletin 650, Bureau of Mines, U.S. Department of the Interior, 1970, p. 1139.

(2) Idem, ibid., p. 1139.

(3) Apatite is a vitreous, sea-green, blue-black, white, etc., transparent-to-opaque calcium chlorophosphate or fluorophosphate, usually crystallizing into hexagonal prisms.

(4) BPL, $Ca_3(PO_4)_2$, describes phosphorus values in terms of tricalcium phosphate (see footnote 3).

P_2O_5 is a very common term used to indicate phosphorus content in rock, and we will generally use this terminology. However, since 1 per cent BPL is equivalent to 0.458 per cent P_2O_5, these terms are not important in themselves.

(5) Wells, Frederick J., The Long-run Availability of Phosphorus: A Case Study in Mineral Resource Analysis, Published for the Resources for the Future, Inc., by Johns Hopkins University Press, Baltimore and London, 1975, pp. xiii and xiv.

(6) Idem, ibid., p. xiv.

(7) Blue, Thomas A., and Thomas F. Torries, Phosphate Rock, Chemical Economics Handbook, Stanford Research Institute, Menlo Park, California, December, 1975, p. 760.0008A. Data adapted from James B. Cathart and R. A. Gulbrandsen, "Phosphate Deposits," United States Mineral Resources, U.S. Geological Survey Professional Paper 320, U.S. Department of the Interior, 1973, pp. 515-525.

Reference and Footnotes to Chapter 1 (continued)

(8) Wells, F. J., _op_. _cit_., p. 11.

(9) _Minerals in the United States Economy_, Bureau of Mines, U.S. Department of the Interior, 1975, p. 62.

(10) Manderson, M. C., "Commercial Development of Off-Shore Marine Phosphates," Arthur D. Little, Inc., Offshore Technology Conference Paper 1658.

(11) For a description of phosphate rock production and a regional description of the phosphate rock industry, see Richard Lewis (1970), and "Phosphate and Potash, Minerals to Feed the World," by John V. Beall and Paul C. Meritt, _Mining Engineering_, October, 1966, pp. 76-99.

(12) The major coal mining company in West Germany is known for its superior land reclamation programs.

(13) In Section 8.6 the reader can find a more complete discussion of the problem of externalities.

(14) Blue, T. A., and T. F. Torries, _op_. _cit_., p. 760.0000B.

2. PHOSPHATE ROCK MARKETS

2.1 Introduction

In an attempt to facilitate understanding of the many factors affecting the phosphate rock market, the discussion has been set out under four separate headings. It is quite clear that these resultant sections in no way compose a set of independent, mutually exclusive and exhaustive subsets. However, in our view this is not required. Despite a considerable interrelationship and overlap between supply conditions, demand conditions, export markets and prices, it is felt that this division improves elucidation.

2.2 Supply Considerations

2.2.1 Domestic

The most complete picture of the U.S. supply can be provided by again referring to the SRI report on phosphate rock. (1) Table 10 shows the U.S. phosphate rock capacity in 1975 and projected for 1980 as compared to the world total. In Table 11 a detailed regional time-series description of capacity and marketable production is presented.

TABLE 10. WORLD PHOSPHATE ROCK CAPACITY

Millions of Tons, Gross Weight

	1975	1980 Projected
United States	53.8 (38.1%)	75.0 (36.1%)
All others	87.3 (61.9%)	132.5 (63.9%)
TOTAL	141.1	207.5

Source: Phosphate Rock by Thomas E. Blue and Thomas F. Torries, Stanford Research Institute, Menlo Park, California; December, 1975, p. 760.0001D. The authors emphasize that these projections were made in late 1975 and do not incorporate subsequent developments which tend to indicate a lower rate of capacity increase.

TABLE 11. CAPACITY AND MARKETABLE PRODUCTION OF PHOSPHATE ROCK; MILLIONS OF SHORT TONS GROSS WEIGHT

	Florida & North Carolina				Tennessee		West		TOTAL United States	
	Capacity									
	Florida	N. Carolina	Total	Marketable Production	Capacity	Marketable Production	Capacity	Marketable Production	Capacity	Marketable Production
1970	32.8	1.5	34.3	31.3	3.1	3.2	5.0	4.3	42.4	38.7
1971	32.9	1.5	34.4	32.2	2.8	2.6	5.2	4.2	42.4	38.9
1972	33.9	1.6	35.5	34.1	2.8	2.2	5.5	4.6	43.8	40.8
1973	33.7	1.7	35.4	34.4	2.7	2.5	5.9	5.2	44.0	42.1
1974	36.0	1.7	37.7	37.0	2.7	2.4	6.6	6.3	47.0	45.7
1975	41.2	2.5	43.7	N/A	2.8	N/A	7.3	N/A	53.8	N/A
1980	54.8	8.7	48.2	N/A	2.5	N/A	8.9	N/A	75.0	N/A

Source: Blue and Torries, *op. cit.*, p. 760.0004S. See note on Table 10.

The most significant feature apparent from these tables is first of all the extremely rapid anticipated growth in capacity for North Carolina. (2) Despite a smaller absolute change from 1976 to 1980 than that of Florida, percentage-wise the change measures about 250 per cent to about 20 per cent in favor of North Carolina. This is partly because of North Carolina's low initial base, but similar low bases of Tennessee and the West show nowhere close to such an expansion. In fact, Tennessee's capacity is expected to fall by about 40 per cent. Another significant point shown by these figures is that of the strong annual growth rate of about 8.5 per cent in total U.S. capacity up to 1980 and especially when compared to the early 70's.

This aspect of the supply picture is not so surprising when these developments are related to what has happened to product prices, however. These price developments will be shown in a subsequent section where the supply and the demand side can be shown together. The point illustrated by these statistics is only that the price elasticity of supply is most probably greater than zero. Any more specific elasticity estimate would be worth a separate study (See 2.6 for discussion and definition of elasticity).

Another way of gaining insight into the supply situation domestically is to follow the approach of the National Economic Analysis Division of the U.S. Department of Agriculture. This approach also encompasses demand factors, since it concentrates on stocks or inventories. More information is needed to determine if changes in stocks are due to unexpected demand conditions or are in fact due to supply conditions. However, in a recent issue of the 1975 Fertilizer Situation (3) much concern is voiced about the production of phosphate rock which "has not kept pace with (these) uses." (4) It then gives the stocks as shown in Table 12.

TABLE 12. TOTAL STOCKS OF PHOSPHATE ROCK, U.S., 1000 TONS

Year Ended June 30	Total Stocks
1971	13,747
1972	12,886
1973	9,660
1974	7,505

Source: 1975 Fertilizer Situation, U.S. Department of Agriculture, p. 5.

One also learns that there is a two-month average inventory above ground in all producing areas in the United States and that this is close to the absolute minimum and "is a precarious position for American agriculture at this time of pressing need." (5)

A similar approach to the "supply situation" (but could indeed be a better reflection of the demand situation) is taken by reports in "Chemical Markets." Here phosphate rock stocks are given in "days of production," and for 1973, 1974, and 1975 the figures were 95, 56, and 98 days, respectively. (6) Thus, the "ominous" trend seen by the 1975 Fertilizer Situation seemed to change considerably in 1975 (even though a lack of comparability of these two different sets of statistics makes analysis difficult).

At this stage it might be appropriate to draw attention to some unfortunate terminology which appears from time to time in reports on the supply situation of phosphate rock. The term "oversupply" is most likely to disturb economists who point out that transactions in the marketplace take place at "equilibrium prices," i.e., at prices which make supply equal to demand where both terms include the possibility of inventory accumulation or depletion. If a "disequilibrium situation" exists, i.e., where supply does not equal demand, prices will either rise or fall and again equalize supply and demand. In reality, prices do not always change instantaneously to equalize supply and demand, and long-term contracts and other "inflexibilities" possibly allow a certain degree of "disequilibrium-trading." Short-run inventory decumulation that is unwanted normally leads to price increases, while inventory accumulation leads to price reduction.

The main point to remember regarding supply, however, is that supplies and capacities are determined by economic forces and reflect the decision-making of largely private firms. Given a world of uncertainties, these decisions do not always prove correct, so that adjustments and compensations need to be made.

One must expect, therefore, to see supplies and capacities change from time to time. In certain circumstances these reflect the existence of regulations, controls, limitations, etc., placed on private firms, but otherwise they reflect the interaction of supply and demand conditions.

Before proceeding, it should be stated that domestic supplies in the "Pacific region" will be discussed in the next section on "foreign" supplies. This might well seem inappropriate, but this is done so as to get some cohesiveness in the analysis of those market areas that are considered to be of major interest to potential southern California phosphate rock producers.

2.2.2 "Foreign"

Tables 1-8 in Chapter 1 give a fairly exhaustive view of the world supply situation. The first table, with all its deficiencies as mentioned earlier, shows where most of the world reserves are located. This information might be indicative of where future supplies will be coming from. Table 2 does the same for the U.S.

Tables 3-8 then show the production and export trade of the major producers and exporters in the world. It can be seen that there is no perfect correlation among the countries as to their share of current production and export trade relative to their apparent share of reserves. The dominance of Africa in the reserves figures, however, seems to be reflected in the rapid export growth of Morocco and developments in the former Spanish Sahara, Algeria, Tunisia, Senegal, and Togo. The production from these areas generally shows higher-than-average rates of growth in production, despite considerable technical problems with some of the rock from Northern Africa due to its high chlorine content (former Spanish Sahara), the organic material content causing foaming in processing (7), and political problems in the former Spanish Sahara.

The largest part of the North African supply is directed toward the eastern and western European markets, however. We assume that potential California marine phosphate rock will not attempt to compete in these areas, but that the markets of interest are those in the Pacific Basin. (8) Therefore, a review of supplies is presented for the major markets that are considered to make up the Pacific Basin, i.e., (I) West Coast States and Hawaii, (II) Mexico and Central America, (III) West Coast of South America, (IV) Australia and New Zealand, (V) Japan, and (VI) Taiwan, Philippines, and South Korea. Sweeney and Bradley, in their 1963 study [see (8)], looked at consumption in these areas, as well as the potential market for California phosphorite rock from the same sources. Developments in phosphate demand, supply, and prices justify new attention to these markets.

Although this analysis was intended to deal exclusively with foreign markets, it is preferable to include those sections of the U.S. which may be considered as possible markets for California phosphorites. In this way a more unified presentation of present and future supplies in potential markets for phosphorites is achieved.

2.2.2.1. West Coast States

It has already been seen in Table 11 that none of the west coast states is listed as a producer. The west includes Montana, Wyoming, Idaho, and Utah. California, Oregon, and Washington are non-producing states.

Phosphate deposits do exist in California, however, (9) but only two are believed to have commercial potential. (10) These are (a) the Pine Mountain deposits, and (b) the Cuyama deposit in Santa Barbara County. The former is located on federal land, in the Los Padres National Forest. The U.S. Gypsum Company has tried, so far unsuccessfully, to get a lease on this federal reserve since the company was granted a prospecting permit effective November 1, 1964.

The history of this application suggests that offshore developments will face similar problems. Sufficient differences between these two cases exist to weaken such comparisons, but it is clear that many industry representatives will find the comparison very real. Even though the California phosphorite deposits are located outside of state and local government jurisdiction, many feel that it is no blessing to fall exclusively within federal jurisdiction. (11) We will return to these problems at a later stage but it might be wise to keep the experience of U.S. Gypsum Company in mind while proceeding with the evaluation of offshore phosphorite mining.

The Cuyama deposit, also on federal land, was leased in 1969 and has about half the P_2O_5 content (i.e., 4-5 per cent) of the Pine Mountain deposit. Mining was conducted in 1969-70 and then suspended owing to economic circumstances. In March, 1974, the Cuyama Phosphate Company proposed resumption of mining activities and in March, 1975, the Santa Barbara Department of Planning granted and then extended a conditional use permit.

The operations of the Cuyama Phosphate Company and the intended operations of U.S. Gypsum are apparently significantly different. The former has been mining on a small scale and the rock has been sold to farmers in San Joaquin Valley for usage "as is"; i.e., the rock is applied directly on the soil and thus serves as a soil conditioner and a fertilizer. There has been considerable debate as to the actual benefits of this rock application (12), but this lies beyond the scope of this report.

The Pine Mountain project would use a "proprietary acid leach process developed for this deposit which would treat the ore as mined, without the usual preliminary beneficiation step. This process has been developed through the pilot plant stage but is not yet commercialized." (13)

No deposits have been discovered in Oregon, Washington, or Hawaii and the only deposits in Alaska are situated on the North Slope. They are said to be of little or no commercial interest at the present. (14)

Various reports on California phosphorites have dealt with the Canadian market as a prospect for California phosphorites. For this reason a few words on Canada and its supplies will be included in this section on the west coast states.

According to the SRI Phosphate Rock report " . . . the deposits in Canada that offer the most potential are the apatite-bearing carbonate complexes in Quebec and Ontario and the widespread sedimentary phosphate-bearing deposits in British Columbia and Alberta." (15) The latter, which are of most interest for this analysis, are low grade. Further, the deposits are deep and underground mining would be required. Recently, IMC has discovered substantial reserves in Ontario and these are reported to be of better quality than existing reserves. At this time, however, insufficient information is available to fully evaluate the impact of these discoveries. Apart from the potential of these reserves, therefore, few or no indigenous supplies of phosphate rock exist in the first region.

2.2.2.2 Mexico and Central America

Mexico is known to have numerous deposits of phosphate, both onshore and offshore. The three deposits offshore from Baja California, with significant quantities of potentially minable reserves of economic grade that have received considerable attention are: (a) San Juanito embayment (the sand deposit), (b) the Ranger Bank (nodules) and the San Jose Bank (nodules). (16)

According to a report prepared for the Mexican companies involved, "a concentration of samples within this 980 square kms delineated an area of 308 square kms within which a minimum of 400 million tons of phosphate sand averaging 7.1 per cent P_2O_5 in place . . . has been proven." (17) Water depth at this deposit is apparently less than 50 fathoms.

Of the other two deposits, the report holds that they contain significant reserves of phosphate nodules of economic grade and that the Ranger Bank is a likely prospect for mining. Water depth at these locations averages about 70 fathoms for Ranger Bank and 65 fathoms for San Jose Bank.

Global Marine was part of the group that has investigated these deposits. In our interview on September 17, 1975, with a representative of the Company, he expressed great confidence in their economic potential. No recent cost estimates of actual mining operations exist but at the prices of phosphate rock in 1975, he felt that the profit margin would be excellent.

According to Global Marine, the Mexican government showed a preference for the exploitation of the nodule deposits of the Ranger Bank and the San Jose Bank. It was apparently felt that these would be most compatible with present operations and plants in Mexico.

The fact remains, however, that more than 10 years after the initial exploration activity these deposits have still not been exploited and, as far as is known, no plans exist for immediate utilization. It is known that a high chlorine content could result if the phosphate sand is washed aboard ship. A subsequent washing with fresh water would in turn cause pollution or waste disposal problems as well as increase the processing cost. An inadequate infrastructure is another factor making exploitation unattractive.

Additional onshore deposits that have generated considerable attention are (a) a pelletal phosphate deposit along the new transpeninsular highway, some 60 miles north of La Paz in Baja California Sur and (b) deposits in Tepezala-Asientos mining region, 30 miles north of Aguascalientes (18). According to the

SRI report " . . . a 1979 on-stream goal has been tentatively established to produce one million tons per year by 1980 and at least three million tons per year by 1985. However, even if the physical characteristics of this resource (e.g., minability, rock quality, actual reserves) prove to be suitable for development, the general lack of infrastructure in the area, the size of the capital investment required, and the location of the deposit vis-à-vis markets suggests that effective exploitation before the early to mid-1980's will be difficult." (19) As for the Tepezala-Asientos deposit, it is only described as "rich" and it is likely that the qualifications expressed by the SRI report are equally appropriate here.

The conclusion for this region, therefore, seems to be that no significant phosphate rock production is likely in the immediate future but that a substantial exploration and evaluation activity is taking place. Thus one should expect production to pick up in the 1980's and possibly provide Mexico with the self-sufficiency it is now anticipating. Of course, developments on the demand side must be analyzed for any more definite conclusions.

2.2.2.3 West Coast of South America

The huge deposits of more than 10 billion tons of estimated marketable phosphate rock, averaging 30 per cent P_2O_5, in the Sechura Desert of Peru probably represent the largest supplies in this region. At Bayovas, on the Pacific near the trans-Andean pipeline terminal, a large integrated mining-industrial complex is being developed and an initial production of 700,000 tons was planned for 1976. (20) Later, the government hopes to attain a yearly production of two million tons of phosphate concentrates, 483,000 tons of phosphoric acid, 200,000 tons of potash and other by-products including industrial salt. Also, major petrochemical and metallurgical complexes are planned for Bayovas using the phosphates, oil, and nearby gas resources. Production does take place at other locations and additional reserves have been reported, but these are apparently nowhere comparable to the scale at Bayovas.

Colombia has undertaken a considerable exploration program together with the U.S. Geological Survey and the U.S. Agency of International Development. Potential reserve/resources are estimated at between 425 and 550 million tons with grades varying from 10 to 29 per cent P_2O_5. Current production is not large and much of the phosphate rock is directly applied to the soil. It is expected that production will increase at a significant rate and that more of the rock will be beneficiated and used to produce fertilizer products.

Chile has known reserves of around 2.5 million tons of 25-28 per cent P_2O_5 rock, about 3 million tons of 10-12 per cent P_2O_5 rock and several small, unexploited deposits of low grade. However, no current production or immediate plans for production are reported.

According to published information based on Peruvian sources, one is likely to see considerable production of phosphate rock very soon owing to the developments in Peru. These sources also lead one to believe that much of the rock will be used as inputs into other products and that little emphasis will be placed on exporting phosphate rock. Thus, even if Peru would not be a market for California phosphorites, it might seem that Peruvian rock will not be a (major) competitor to California phosphorites in other Pacific Basin markets. Several well-informed sources, however, have taken issue with such conclusions based on information coming out of Peru. Rather, it is felt that the domestic needs for phosphate rock in Peru will lag behind supply and that a substantial quantity of rock will be exported into the Pacific Basin. If this does happen, it is clear that any potential California offshore phosphorite producer will most likely be adversely affected. Of the other countries, only Colombia seems to be striving to reach self-sufficiency but in reality is likely to need foreign supplies. This is even more true of Chile unless a rapid change in developments takes place there.

2.2.2.4 Australia and New Zealand

As is true for most mineral deposits in Australia, phosphate deposits are large. The identified reserves of the two major concessionaires, BH South and International Minerals and Chemicals, are reported to contain about 3.1 billion tons of ore. These onshore deposits are mostly about 17 per cent P_2O_5, but a 45 million ton section of BH South's reserves are as high as 31 per cent.

Despite these large deposits and the existence of numerous smaller onshore and offshore deposits, production so far has been modest. This has probably been due to adequate supplies from island sources in the Indian and Pacific Oceans; but increased production costs, higher prices, and dwindling supplies from these islands have made domestic supplies more attractive. BH South started rock shipments last year and by 1980 these are expected to reach two to three million tons per year. International Minerals and Chemical Company (IMC) has not announced any development plans.

New Zealand has little or no current production and the major phosphate deposit discussed in the literature is that of the Chatham Rise. These deposits are discussed extensively by David Pasho in his thesis <u>Character and Origin of Marine Phosphorites</u> (21), which deals mainly with southern California deposits. The SRI report quotes a total deposit figure of 135 million tons of nodules, of which 70 million tons are thought to be recoverable. Mining and beneficiation tests have apparently been undertaken, and the evaluation points to a favorable economic potential for these deposits. A further discussion of these New Zealand deposits and their potential will be undertaken in connection with the evaluation of the southern California deposits. This fourth region of attention, therefore, is likely to see increasing indigenous supplies, at least in Australia, and here reserves appear to be sufficient for the domestic market. It is clear, however, that some of the reserves are in inaccessible regions with an unsatisfactory infrastructure so that the cost of production is uncertain. Whether some of these deposits will be exploited depends upon both production costs and prices of competing supplies including potential southern California supplies.

2.2.2.5 Japan

No production or reserve statistics have been found for Japan and the implication is that both are zero or insignificant. This reasoning seems very much in line with the conclusions of most previous studies which see Japan as the most promising export market for California phosphorite rock. This view will be considered later in this chapter after the demand section has been completed. At that time one will be in a better position to see what supplies other producing areas have available for export, and by analyzing time-series data available it may be possible to draw some tentative conclusions.

2.2.2.6 Taiwan, Philippines, and South Korea

Production and reserve figures are lacking also for these countries and one is forced to the same conclusions as for Japan. In terms of potential markets, however, these are still not likely to be as significant as that of Japan, but the next two sections will be more conclusive on this point.

2.3 Demand Considerations

2.3.1 Domestic

To stress the interdependence between this demand section and the previous supply section, it might be illuminating to start considering some time-series data on phosphate rock supply/demand relationships for 1964-73 (See Table 13). In Fig. 5 a flow diagram for 1973 is presented. These statistics are not particularly detailed, but they will be extended in subsequent tables.

A more accurate picture of domestic conversion of rock with a more correct statistical base, dealing in tons of P_2O_5, is given in Fig. 6, which has been taken from SRI's Phosphate Rock report (22). We may note that phosphate rock exports are not included here since the figure deals exclusively with domestic conversion of rock. In the next section, however, rock exports will be considered.

It should be clear by now that the great bulk of phosphate rock is used for fertilizer; the domestic conversion of rock may, therefore be detailed appropriately by relating it to the "primary market" (See Table 14).

The statistics of Table 13 appear somewhat suspect in that each of the five demand classifications increased by 24.2 per cent from 1965 to 1970. In the period 1970-73, however, fertilizers increased by 14.1 per cent, detergents by 6.4 per cent and animal feeds, food products, and "other" by 26.4 per cent. The identical

TABLE 13. PHOSPHATE ROCK SUPPLY-DEMAND RELATIONSHIPS, 1964-73; THOUSANDS OF SHORT TONS

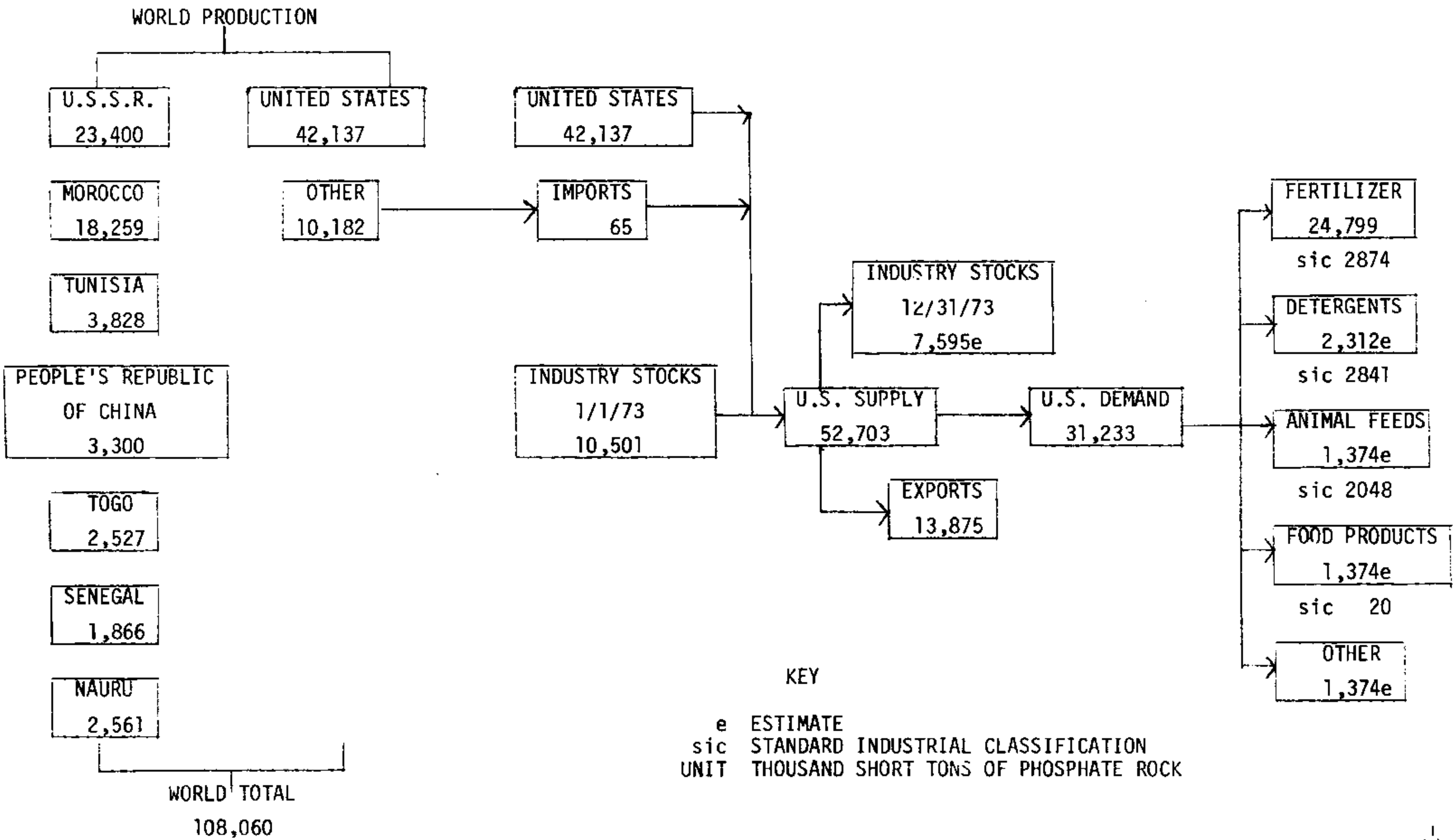
	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
World production:										
United States	25,715	29,482	39,044	39,770	41,251	37,725	38,739	38,886	40,831	42,137
Rest of world	37,004	40,816	44,150	46,144	51,326	52,873	54,896	53,622	58,150	65,923
TOTAL	62,719	70,298	83,194	85,914	92,577	90,598	93,635	92,508	98,981	108,060
Components of U.S. supply:										
Domestic mines	25,715	29,482	39,044	39,770	41,251	37,725	38,739	38,886	40,831	42,137
Imports	175	148	178	139	116	140	136	84	55	65
Industry stocks, Jan. 1	5,140	6,123	6,529	10,118	9,942	13,943	13,697	14,566	11,951	10,501
TOTAL of U.S. supply	31,030	35,753	45,751	50,027	51,309	51,808	52,572	53,536	52,837	52,703
Distribution of U.S. supply:										
Industry stocks, Dec. 31	6,123	6.529	10,118	9,942	13,943	13,697	14,566	11,951	10,501	7,595
Exports	6,374	7,323	9,248	10,072	12,099	11,336	11,738	12,587	14,275	13,875
Demand	18,532	21,866	27,382	27,902	25,336	25,534	27,163	27,788	29,535	31,233
Apparent surplus (+), deficit (-) supply*	+1	+35	-997	+2,111	-69	+1,241	-895	+1,210	-1,474	------
U.S. demand pattern:										
Fertilizer	14,826	17,492	21,906	22,322	20,269	20,428	21,730	22,230	23,629	24,799
Detergents	1,483	1,749	2,191	2,232	2,028	2,043	2,172	2,222	2,363	2,312
Animal feeds**	741	875	1,095	1,116	1,013	1,021	1,087	1,112	1,181	1,374
Food products**	741	875	1,095	1,116	1,013	1,021	1,087	1,112	1,181	1,374
Other**	741	875	1,095	1,116	1,013	1,021	1,087	1,112	1,181	1,374
U.S. primary demand	18,532	21,866	27,382	27,902	25,336	25,534	27,163	27,788	29,535	31,233

* The difference between distribution of U.S. supply and total U.S. supply.

** These identical figures would seem to reflect the assumptions of the estimation methods.

Source: Minerals in the U.S. Economy, Bureau of Mines, U.S. Department of the Interior, 1975.

FIG. 5. SUPPLY-DEMAND RELATIONSHIPS - 1973; PHOSPHATE ROCK

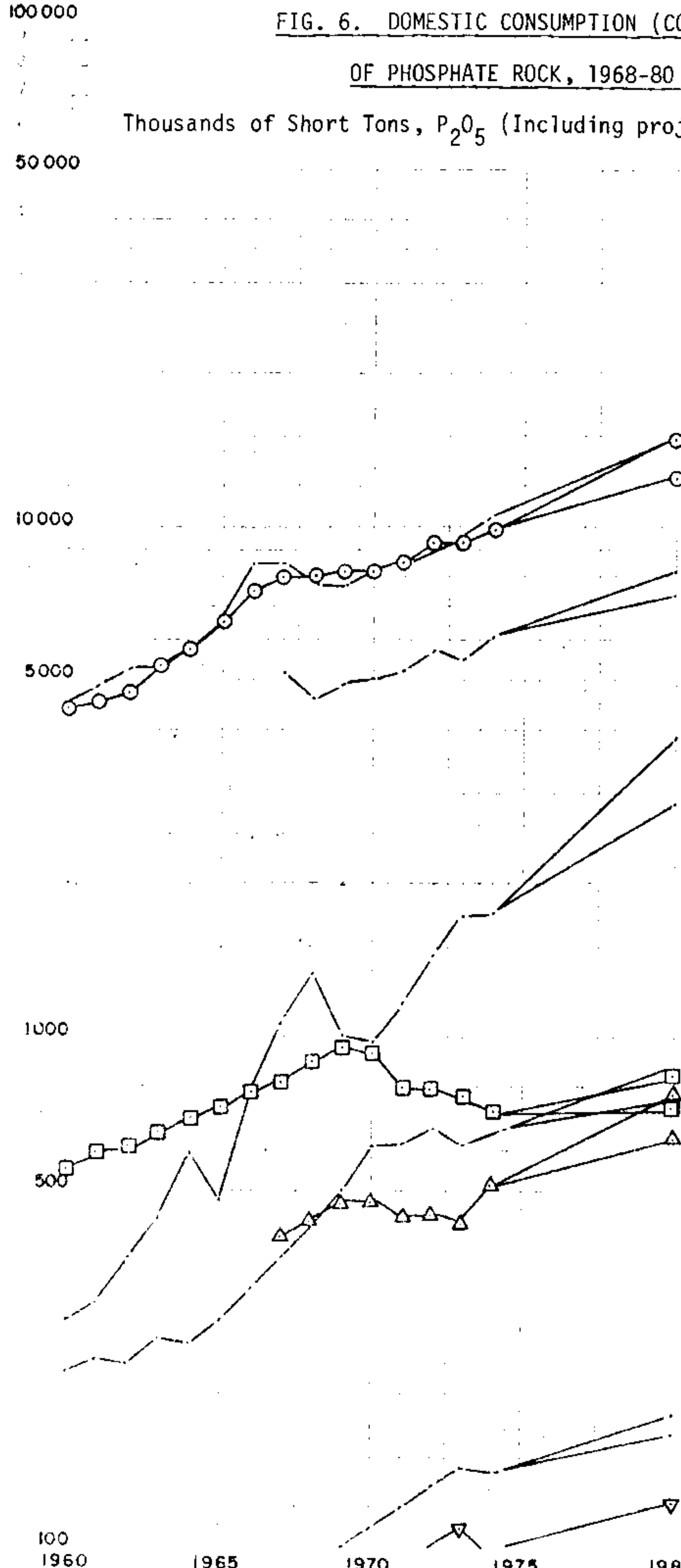


Source: Minerals in the U.S. Economy, Bureau of Mines, U.S. Department of the Interior, 1975.

FIG. 6. DOMESTIC CONSUMPTION (CONVERSION)

OF PHOSPHATE ROCK, 1968-80 (23)

Thousands of Short Tons, P_2O_5 (Including projections for the period 1974-80)



	TONNAGE 1974p*	TONNAGE 1980	AVERAGE ANNUAL GROWTH RATE 1974-80
A TOTAL APPARENT CONSUMPTION	10,578	12,500-14,600	3.6-6.2%
TOTAL CONSUMPTION BY PRODUCT/MARKET B ⊙	9,927		
FERTILIZERS FOR DOMESTIC CONSUMPTION C	6,111	7,300-8,100	3.1-5%
FERTILIZERS FOR EXPORT D	1,720	2,875-3,825	8.5-13.25%
LIVESTOCK AND POULTRY FEEDS E	650	750-850	2.5-4.75%
BUILDERS AND WATER TREATMENT F ⊡	701	720-820	0.5-2.5%
ALL OTHER (Domestic and Export) △ G	508	640-740	4.25-7%
H FOODS, BEVERAGES, PET FOODS, DENTIFRICES	141	165-178	2.8-4.1%
DIRECT ACID TREATMENT OF METAL SURFACES I ▽	96	90-120	(-1)-3.8%

*p. preliminary.

Source: Blue and Torries, op. cit., p. 760.0006G.

TABLE 14. DOMESTIC CONSUMPTION (CONVERSION) OF PHOSPHATE ROCK

(Thousands of Short Tons, P_2O_5)

BY PRIMARY PRODUCT

(Domestic and Export)

	WET-PROCESS PHOSPHORIC ACID	PHOSPHORUS	NORMAL SUPERPHOSPHATE	CONCENTRATED SUPERPHOSPHATE (Direct Rock Feed)	DEFLUORINATED PHOSPHATE ROCK	TOTAL
1960	1,489	1,128	1,411	280	117	4,425
1961	1,584	1,188	1,386	291	120	4,569
1962	1,773	1,246	1,348	273	119	4,759
1963	2,200	1,345	1,363	316	134	5,358
1964	2,558	1,390	1,340	348	143	5,779
1965	3,255	1,530	1,240	416	139	6,580
1966	4,042	1,560	1,264	482	155	7,503
1967	4,488	1,618	1,316	421	137	7,980
1968	4,667	1,690	1,016	394	129	7,896
1969	4,865	1,718	897	385	141	8,006
1970	5,218	1,646	744	419	172	8,199
1971	5,638	1,503	696	430	175	8,442
1972	6,491	1,492	752	471	170	9,376
1973	6,653	1,450	688	481	149	9,421
1974 preliminary	7,026	1,445	776	490	191	9,927
Annual rate of growth	11.72%	1.78%	-4.18%	4.08%	3.56%	5.94%

Source: Blue and Torries, op. cit, p. 760.0006F.

data for these last categories also make the numbers suspect. In terms of annual rate of growth from 1964 to 1973, the figures are 5.9, 5.1, and 7.1 per cent respectively for fertilizers, detergents, and animal feeds, food products, and others.

The SRI estimates for a somewhat different classification probably give a better picture of the developments, even though the statistical basis of the P_2O_5 content may hide significant substitutions between products.

The statistics from Fig. 6 show that annual percentage rates of growth for the five years 1969-74 are 6.3, 4.4, 4.36, 11.57, 6.08, -5.78, 1.31, 7.99, and 5.34 for A through I, respectively. A further examination of Fig. 6 shows a considerable variation from year to year in some of the series. Some divergence also exists between the growth rates calculated for this five-year span and what the SRI study projects for the 1974-80 period. For B, C, and D, the figures of the five-year period fall inside the projection, but for A, E, H, and I, the projections are lower than the growth rates for the five years. For F and G, which showed a decrease or little growth, the projection anticipates a recovery and thus higher rates of growth.

From Table 14 the outstanding feature is the extremely high annual growth rate of wet process phosphoric acid, calculated at 11.72 per cent for the period shown, and the poor showing of normal superphosphates, calculated as -4.18 per cent annual rate of growth. For the other primary products, phosphorus shows the least growth, at 1.78 per cent annual rate, defluorinated phosphate rock comes in at 3.6 per cent, and concentrated superphosphate shows a 4.08 per cent annual rate of growth.

Since this study is taking phosphate rock as the basic product of analysis, no attempt is made to determine what derivative products would be most profitable. A company mining phosphorites could obviously decide to process the basic rock further and sell derivative products, or it might already be in this business and need the rock for this specific reason. This type of analysis will not be pursued as it would obviously require considerable time and effort and make this part of the report inordinately large.

Since fertilizer is the major end product of phosphate rock, and since the Pacific region is of most interest, this discussion of domestic demand will end with Table 15 which shows the use of phosphorus as fertilizer for the Pacific states.

TABLE 15. USE OF PHOSPHORUS AS FERTILIZER, BY STATES, YEARS ENDED JUNE 30, 1969-70, 1000 TONS OF AVAILABLE P_2O_5

State	1969	1970	1971	1972	1973	1974
California	141.8	146.4	170.0	177.7	178.8	182.8
Oregon	40.0	44.9	42.7	41.9	49.1	44.9
Washington	46.0	44.7	46.4	50.7	63.2	71.0
Hawaii	15.6	19.1	16.8	22.1	19.4	16.0
TOTAL	243.4	255.1	275.9	292.4	310.5	314.7

Source: 1975 Fertilizer Situation, Economic Research Service, U.S. Department of Agriculture.

California clearly dominates the consumption of phosphates for fertilizer use, with close to 60 per cent. The statistics also show a lack of large changes in either absolute levels or relative shares, and projections can therefore be made with a high degree of confidence.

2.3.2 "Foreign"

There is necessarily a substantial overlap between this subsection of demand and the next section of exports. For certain countries with little or no domestic phosphate rock production, import figures will reflect their consumption but for other countries the correlation between the two sets of statistics will be substantially less.

Since the indigenous supply situation in those markets upon which this study will concentrate has already been evaluated, it should be sufficient to assess the export statistics, which will be done in the next section. These two pieces of information should reflect rather well the demand picture and indicate what competition can be expected for southern California phosphorites in a particular market.

Before going on to the next section, however, it might be worthwhile for an overall view of phosphate consumption, to report some world rock statistics for 1964, 1965, and 1970, the consumption of P_2O_5 in selected years, and a projection for 1980. These statistics are found in Tables 16, 17, and 18.

TABLE 16. PHOSPHATE ROCK CONSUMPTION, 1000 METRIC TONS OF ROCK

Demand Sector	1964	1965	% Change
North America	18,144	21,207	16.9
Western Europe	13,569	14,600	7.6
Asia	3,310	3,596	8.6
Australia	3,473	3,569	2.8
Africa	1,637	1,958	19.6
Latin America	737	732	-0.7
Communist Europe and U.S.S.R.	13,409	14,932	11.4
Communist Asia	2,155	2,455	13.9
WORLD TOTAL	56,394	63,049	11.8

Source: Overall, M. P., "Mining Phosphorite from the Sea, Part 1, Market Structure and Geology," Ocean Industry, September, 1968.

TABLE 17. WORLD PHOSPHATE ROCK CONSUMPTION BY AREA, 1970

MILLIONS OF LONG TONS OF PRODUCT

North America	25
South America	1
Western Europe	18
Eastern Europe & U.S.S.R.	18
Africa	4
Japan	4
Rest of Asia	3
Oceania	5
TOTAL	78

Source: Manderson, M. C., "Commercial Development of Offshore Marine Phosphates," Offshore Technology Conference, Paper No. 1658.

TABLE 18. WORLD PHOSPHATE ROCK CONSUMPTION, MILLION METRIC TONS P_2O_5

(ACTUAL AND PREDICTED)

Year	Tons	Annual Rate of Growth, %
1965	13.7	
1968	17.1	1965 - 1975[a]: 5.9%
1970	18.6	1975[a] - 1980[a]: 3.8%
1973[a]	22.3	
1975[a]	24.3	
1980[a]	29.3	

a: Preliminary revision on the basis of higher-than-anticipated utilization of production capacity.

Source: Lehr, James R. and Guerry H. McClellan, "Phosphate Rocks: Important Factors in their Economic and Technical Evaluation," published in The Mining and Beneficiation of Fertilizer Minerals, Mining and Beneficiation of Phosphates; Central Treaty Organization, Istanbul, Turkey.

Two factors which stand out in the previous tables are (1) the overwhelming dominance of (a) North America, (b) Western Europe and (c) Eastern Europe and U.S.S.R., and (2) the high rate of growth in demand in the 1960's as compared to that in the 1970's. This first result should not really come as a surprise when income levels and the degree of intensified agriculture in these areas are considered. The second conclusion could be due to a slower rate of increase in real income in the 70's as well as to a degree of saturation in certain applications of phosphate fertilizers.

With this overall perspective on world phosphate consumption, phosphate exports that move into and out of the Pacific Basin in particular are analyzed.

2.4 "<u>Export Markets</u>" (24)

A good overall view of world exports can be obtained from Tables 4 through 8 in Chapter 1. These cover exports of the U.S., U.S.S.R, Morocco, a group of major African and Middle Eastern producers, and finally offshore Asia and Oceania. The period covered is obviously very short for any definitive conclusions, or trends to be perceived, and when the five regions start from such different bases it is also hazardous to compare annual rates of growth. If the latter are derived, however, they show a 39.6 per cent annual rate of growth for offshore Asia and Oceania. But this high growth rate is mainly due to the huge increase from 1970 to 1971. For 1971-74 the rate of increase was down to 8.4 per cent.

The others show more "normal" rates of growth of 4.9, 5.8, 13.4, and 15.2 per cent for the first four "regions," respectively, but Morocco and the African-Middle Eastern "regions" exhibit very high annual rates of growth for 1972-74 of 17.4 and 25.3 per cent, respectively.

Since the Pacific Basin as defined and discussed in the previous two sections is of most interest, these markets will now be examined in more detail. Already a fairly good picture of the indigenous supplies in these markets has been provided in Section 1 in this chapter. Trade taking place here will now be considered. This will give a better picture of how each of the areas is provided with phosphate, and what areas or countries are likely to offer the greatest competition for future southern California phosphorite producers.

2.4.1 West Coast States

Due to the particular approach taken here and on the basis of the definition which allows the inclusion of the western part of Canada--more specifically British Columbia--consideration will first be given to trade flows in markets which might have high potential for California offshore producers.

In the report "Mining Phosphorite from the Sea," by M. P. Overall, the western U.S. and Canadian markets "of particular significance to any prospective offshore California and Baja California phosphorite venture" (25) are said to amount to some 930,000 short tons of P_2O_5 or about 3.3 million short tons of 31.5 per cent rock in 1966. Of this, some 507,000 short tons of P_2O_5 were in the U.S. Various reasons are given, however, why this total should not be considered as a potential market for offshore producers. We will return to these reservations after first looking closer at total demand, and thus imports, of phosphate into the "western states."

In their 1963 paper, Sweeney and Bradley reported that California, Oregon, and Washington consumed 150,000 short tons of P_2O_5 as fertilizers in 1961. (26) Of this total they assumed that 50 per cent involved the importation of rock into these states, while the rest was imported as finished fertilizer products.

Looking at Table 15 of Chapter 2 one can see what amounts of P_2O_5 were consumed as fertilizer in the years from 1969 to 1974, including Hawaii, and it appears that consumption of P_2O_5 has more than doubled since 1961. The total in 1974 was 314,700 tons, out of which California consumed 58.08 per cent, or 182,800 short tons. It is assumed that the data reported by the U.S. Department of Agriculture only cover the amounts of phosphate used for fertilizer applied to crops in these states. Therefore, these statistics completely exclude that amount of phosphate rock which is imported into these states and used in the production of fertilizers which are then exported to other states and foreign markets. The lack of easily accessible statistics on this point precludes saying anything about the size of this potential market for rock.

One reason why the 182,800 short tons of P_2O_5 used in California in 1974 (or 91,400 short tons if it is assumed that only 50 per cent of P_2O_5 consumption involved the importation of rock) might be an understatement of the rock market for fertilizer uses, or at least might result in a too-conservative projection for future years, is the estimated need of about 500,000 short tons of 32-33 per cent P_2O_5 rock in 1976 by Valley Nitrogen Producers, Inc. (27) This estimated rock requirement is based on the rock needs for their new plant which was scheduled to go into operation in 1976. If a grade of 32.5 per cent P_2O_5 yields a requirement of 162,500 tons of P_2O_5, this estimate is extremely close to the total 1974 P_2O_5 consumption in California.

So far this study has dealt exclusively with rock requirements for fertilizer uses. It is known that the latter represent about 76 per cent of total U.S. rock consumption. (28) Assuming this national average to hold for the western states in particular, then one can infer California consumption of about 240,500 short tons of P_2O_5 instead of the 182,800; or about 414,100 short tons for combined California, Oregon, Washington, and Hawaii instead of 314,700 short tons. Again, however, it is not known what portion of non-fertilizer phosphate products are produced in these four states from rock imported from other states. It could be that the major portion of these non-fertilizer products is imported as "finished products" and thus could represent a lesser potential market to offshore producers. If rock is produced cheaply enough, however, there is no reason why these finished products could not be produced in these states.

The Canadian market is at present almost exclusively supplied by the United States. In Table 19 one can see how this phosphate rock trade has developed since 1968. (29)

TABLE 19. U.S. EXPORTS OF PHOSPHATE ROCK TO CANADA, 1000 SHORT TONS

	1968	1969	1970	1971	1972	1973	1974
	2,306	2,439	2,237	2,647	2,946	3,479	3,899
Yearly % Change		5.77	-8.20	18.33	11.30	18.09	12.07

Annual rate of growth 1968-74: 9.15%

Source: Blue and Torries, op. cit., p. 760.0006Q. See footnote (7) on page 17.

Assuming total U.S. exports to the Canadian market to have been around two million tons in 1966, then the 423,000 short tons assumed by Overall as representing the Western Canadian market of interest to phosphorite producers, would account for slightly more than 21 per cent of the total Canadian market. Using 20 per cent and taking the total Canadian market as four million short tons in 1974, this yields an 800,000 short ton rock market of interest to southern California phosphorite producers. If one uses a 32 per cent P_2O_5 rock, this yields a market of 256,000 short tons of P_2O_5.

Our various assumptions are clearly rather tenuous ones, but in the absence of good statistics for phosphate consumption and imports into the western states in Canada, these will have to suffice. An indication that these estimates are not too far off target, however, is the figure of 0.6 million tons of rock given Manderson (29) as representing rock flows from the U.S. into the western part of Canada in 1970.

These admittedly rough derivations give a total of about 670,100 short tons of P_2O_5 in this western market of North America (excluding Mexico) of which the U.S. market represents about 62 per cent and the Canadian part about 38 per cent. If one is talking about a 32 per cent P_2O_5 rock, this yields a market of about 2.094 million tons of rock. This figure must be viewed as very tentative, however. Several of the assumptions are questionable and the problem of deducing the size of the phosphate rock market in these western states from statistics on the consumption of P_2O_5, mainly in the form of fertilizers, is a fairly intricate problem. Even with good statistics on fertilizer production in each of the states it would require very detailed specifications on what types of fertilizer are produced, etc., to derive a final phosphate rock consumption estimate.

Even though Overall's market estimate was 3.3 million tons of 31.5 per cent P_2O_5 rock, this was considerably reduced when (a) the extent of "captured markets," (b) the extent of existing long-term contracts and (c) the prohibitive rail freight cost from California to these markets were considered. The final conclusion of Overall is that "an immediate western U.S.-Canada market of some 200,000 to 250,000 short tons of rock might be available to an offshore producer dependent on his mining costs." (30)

A much more detailed analysis must be undertaken before the potential market for southern California phosphorite producers can be determined, and this analysis is only intended as a first step in this direction. However, we do not necessarily agree with Overall and other analysts who tend to put heavy emphasis on points (a) and (b) above. Reliance on the "captured market" theory is not viewed as particularly attractive or useful, since this theory appears exceedingly restrictive and would seem to deny that integrated companies behave rationally, in the sense of maximizing profit. If these integrated firms can buy offshore phosphate rock at a cost below that of their own supplies, why should they pass up this profit opportunity?

Long-term supply contracts do not reduce the phosphate rock market available to new producers to the extent that many have believed. First, how many of these long-term contracts exist and, secondly, how many of them elapse at the same time? It seems obvious that these contracts will not all extend for the same number of years from the date a potential offshore producer starts operations. Instead, some are likely to terminate each year and, if offshore rock were competitive, buyers would consider alternative supplies and their respective costs. Obviously, conditions could exist to make supplier-loyalty significant and the ever-varying composition of phosphate rock supplies is one possible reason why one might not see a significant "merchant market." Offshore rock may be of inferior quality due to its composition, and may not be competitive for this reason. Implications for market demand caused by the physical nature of offshore rock will be considered later in the report.

The estimates of Overall, therefore, are exceedingly restrictive and should probably be raised by a factor of between two and four. In fact, if Overall's figure is multiplied by a factor of four, a market of about one million short tons of rock in 1966 results. Assuming an annual rate of growth of 9 per cent, this would yield a market of about two million short tons in 1974. This rate of growth might appear excessive when related to world rates of growth in consumption shown in Table 18 and to recent rates of growth in demand. When related to the higher rates of growth in the 60's, however, this assumption is not out of line. This brings the figures very close to the potential market that was tentatively concluded for phosphorites in 1974.

2.4.2 Mexico and Central America

The available statistics are inadequate for many of the countries of this study, but they should at least give an idea of the magnitudes involved.

In Table 20 the main suppliers of phosphate rock to Mexico have been identified.

TABLE 20. MEXICAN PHOSPHATE ROCK IMPORTS, 1000 SHORT TONS

From:	1968	1969	1970	1971	1972	1973	1974
Nauru*	0	0	0	0	0	0	0
Israel	0	0	67	28	0	0	0
Morocco	0	10	0	281	365	463	733
U.S.	369	822	902	932	861	1,071	966
TOTALS	369	832	969	1,241	1,226	1,534	1,699

*25,000 s. tons in 1975.

Source: Selected statistics from Blue and Torries, loc. cit.

The tremendous rate of growth in Mexico's rock imports (an annual rate of growth of 28.98 per cent since 1968) clearly shows why Mexico is now attempting to develop its own sources of supply. This high rate of growth, partially supplied by rock from Morocco, would seem to imply a potential market for California phosphorite rock. This is not necessarily so, however, and the apparent lack of infrastructure and transportation facilities, which has held back the development of Mexico's own supplies, could make it difficult to get southern California rock from west coast Mexican ports to the processing facilities at various markets in Mexico.

Also, the rich offshore sand and nodule deposits as well as the numerous onshore discoveries point to a high rate of domestic phosphate mining in the 1980's. If these developments are slowed down because other development projects are deemed more urgent relative to the capital available, then California producers could find the Mexican market worthy of attention. Also, if ports and other infrastructure developments are completed along the west coast of Mexico, this would be even more advantageous to California producers.

As for the Central American market, few significant statistics have been found to indicate the presence of much market potential for offshore producers in California. Costa Rica is currently importing about 6000 short tons of rock from the U.S.--an amount which could easily rise considerably. This is not likely to be a significant market and no offshore project is likely to pay much attention to it in its evaluations.

2.4.3 West Coast of South America

The conclusions with regard to Central America can probably be drawn for this area as well. As can be seen in Table 21, existing exports to these countries are rather small and it is unlikely that significant markets for southern California rock producers will develop in this area in the near future.

TABLE 21. EXPORTS OF MAJOR PRODUCERS OF PHOSPHATE ROCK TO THE WEST COAST OF SOUTH AMERICA, 1000 SHORT TONS

From:	1968	1969	1970	1971	1972	1973	1974
Tunisia	0	0	13	0	69	94	0
Former Spanish Sahara	0	0	0	0	0	46	0
Senegal	0	0	0	0	0	0	17
Morocco	0	15	25	0	0	0	0
U.S.	88	27	86	91	93	197	200
TOTAL	88	42	124	91	162	337	217

Source: Selected statistics from Blue and Torries, loc. cit.

2.4.4 Australia and New Zealand

For these two countries the available information is somewhat better, even though still inadequate for complete confidence. The statistics which are published by the United Nations cover 1966, 1967, and 1970, and include volumes and values (31), while the data supplied in the SRI Phosphate Rock report cover the period 1971-75. The latter are calculated from the major world exporters, however, and are therefore likely to underestimate the actual import figures of Australia and New Zealand.

TABLE 22. AUSTRALIAN IMPORTS OF NATURAL PHOSPHATES*

1000 METRIC TONS AND IN 1000 U.S. DOLLARS

	1966		1967	
	Tons	Dollars	Tons	Dollars
World	3,351	30,896	3,303	33,997
Oceania	2,252	20,810	2,454	24,771
U.S.	778	7,017	622	6,727
Chile	0	0	17	130
Morocco	34	415	31	540
Senegal	75	698	45	461
Togo	210	1,941	132	1,369

	1970	
	Tons	Dollars
World	2,374	27,934
Other Asia	719	8,598
South Pacific	1,598	18,732
Morocco	58	603

*Whether or not ground, S.I.T.C. 271.3.

Source: Foreign Trade Statistics of Asia and the Pacific, UN, Vol. IX, Series A, Vol. I.

TABLE 23. AUSTRALIAN IMPORTS OF PHOSPHATE ROCK AS CALCULATED FROM STATISTICS OF MAJOR EXPORTERS TO AUSTRALIA, 1000 SHORT TONS

From:	1971	1972	1973	1974	1975
Nauru	1,192	970	1,684	1,682	1,010
Christmas Island	723	534	920	1,221	1,126
Morocco	53	32	55	57	0
TOTAL	1,968	1,536	2,659	2,960	2,136

Source: Selected statistics from Blue and Torries, loc. cit.

TABLE 24. NEW ZEALAND IMPORTS OF NATURAL PHOSPHATES*, 1000 METRIC TONS, AND 1000 U.S. DOLLARS

	1966		1967	
	Tons	Dollars	Tons	Dollars
World	1,269	21,466	846	15,440
Malaysia	17	281	0	0
Singapore	10	168	18	289
Australia	92	1,423	169	2,496
Oceania	725	12,151	522	9,733
U.S.	290	5,134	136	2,922
Polynesia	135	2,305	0	0

Table 24 (continued)

	1970	
	Tons	Dollars
World	1,028	19,069
Australia	267	4,710
South Pacific	740	13,673
U.S.	22	686

* Whether or not ground, S.I.T.C. 271.3.

Source: Foreign Trade Statistics of Asia and the Pacific, UN, Vol. IX, Series A, Vol. I.

TABLE 25. NEW ZEALAND IMPORTS OF PHOSPHATE ROCK AS CALCULATED FROM STATISTICS OF MAJOR EXPORTERS TO NEW ZEALAND

1000 SHORT TONS

From:	1971	1972	1973	1974	1975
Nauru	649	400	675	406	373
Christmas Island	166	321	421	442	419
TOTAL	815	721	1,096	848	792

Source: Selected Statistics from Blue and Torries, loc. cit.

These statistics show a clear and definite decrease in Australian imports of phosphate rock from 1966 to 1972. Although somewhat higher, Australian import figures substantiate this trend and show the decline from a level of 3.69 million metric tons in 1967 to a level of 1.82 million metric tons in 1971. (32) Also, the value drops from 32 million

$A in 1967 to 18 million $A in 1971. From the SRI statistics, however, one sees a substantial recovery in volume in 1973 and 1974, but then in 1975 another substantial decrease is evident. And as will be seen in the next section on prices, this is possibly due to a large extent to the severe price rise in 1975.

Despite these substantial decreases in importation of phosphate rock by Australia and New Zealand, these countries still constitute a substantial market of close to three million tons in 1975. The very special role of Nauru and Christmas Island in this phosphate trade (33), however, makes these markets harder to penetrate by outside suppliers. These islands will have a substantial transportation advantage against most other suppliers. Mining by draglines and clamshell buckets would appear to be less costly than that of many other operations, especially those requiring underground or offshore mining. No statistics are available on the costs of production; and the costs of imported rock, as derived from the values in Tables 22 and 24, are likely to be less than trustworthy. The lack of uniformity in the phosphate rock imported from different sources, plus variations from shipment to shipment, makes it even more difficult to calculate the cost per ton of imported phosphate rock. What should be expected, however, is that the landed cost of the same grade and quality of rock would be rather close regardless of its origin. In any case, if the markets are reasonably competitive this would be the expected result.

The quality of the rock from Nauru and Christmas Island is high, and supplies are likely to last at least through the 1980's. One must not expect, therefore, that southern California offshore producers will be able to make any major inroad into these markets. Again the reader must be warned that this is a highly tentative conclusion. In the final analysis, the actual quality of the offshore rock as well as the cost of production will be the decisive factors.

2.4.5 Japan

The statistics of Japan's phosphate rock imports show why this country has frequently been claimed as a major potential market for any southern California offshore rock producer. Also, knowledge as to which countries are exporting phosphate rock to Japan and of the origin of rock within countries makes this market appear attractive to new producers. Tables 26 and 27 show Japan's imports by source country.

TABLE 26. JAPAN'S IMPORTS OF PHOSPHATE ROCK

1000 METRIC TONS AND 1000 U.S. DOLLARS

	1966		1967	
From:	Tons	Dollars	Tons	Dollars
World	2,559	51,106	2,632	52,579
Israel	44	764	39	662
Jordan	10	176	8	154
U.S.	1,753	33,007	1,886	35,701
Morocco	327	7,337	410	9,459

Table 26 (continued)

From:	1966 Tons	1966 Dollars	1967 Tons	1967 Dollars
Senegal	204	4,870	171	4,076
Togo	119	2,678	108	2,362
Tunisia	8	134	10	166
Polynesia	93	2,139	0	0

From:	1968* Tons	1968* Dollars	1970 Tons	1970 Dollars
World	3,417	71,563	3,125	67,592
U.S.	2,519	50,178	1,848	36,074
Morocco	464	11,227	587	14,883
Senegal	198	4,964	151	3,771
North Vietnam	0	0	4	104
Israel	0	0	22	387
South Pacific	0	0	373	9,110
Togo	147	3,378	139	3,230

Source: Foreign Trade Statistics of Asia and the Pacific, UN, Vol. IX, Series A, Vol I.

*Source: Foreign Trade Statistics of Japan, 1969, Japan External Trade Association, p. 79.

TABLE 27. JAPAN'S IMPORTS OF PHOSPHATE ROCK AS CALCULATED FROM STATISTICS OF MAJOR EXPORTERS TO JAPAN, 1000 SHORT TONS

From:	1971	1972	1973	1974
Nauru	218	108	165	290
Jordan	53	198	214	284
Israel	34	23	2	20
Togo	0	86	109	73
Former Spanish Sahara	0	24	133	356
Senegal	121	107	126	107
Morocco	504	502	690	696
U.S.	2,171	2,220	2,174	2,490
TOTAL	3,101	3,268	3,613	4,316

Source: Selected statistics from Blue and Torries, loc. cit.

Table 27 probably underestimates somewhat the full extent of Japan's imports, since only major exporters are considered. In spite of this, Japan's imports show an annual rate of growth of 6.8 per cent since 1966. This is a particularly high growth rate when related to that of Australia and New Zealand over the same period.

In "An economic evaluation of markets for California phosphorite deposits," Sweeney and Bradley assume that potential southern California producers could have captured 58 per cent of the 464,000 tons of P_2O_5 consumed in Japan in 1960-61. If a similar assumption is used, the potential share in Japan's 1974 market would be 2.512 million tons of rock. This might not be such an outrageous assumption when related to the 2.5 million tons presently fed to this market by U.S. suppliers, most of which comes from Florida.

A California offshore producer could possibly have a substantial transportation cost advantage vis-à-vis Florida producers, and this could also be the case vis-à-vis the North African and Middle Eastern producers. One must conclude, therefore, that a substantial market potential could be captured by southern California producers. Again, it clearly will depend on both the quality of the rock that can be produced in southern California (since a large part of Japan's imports is high-quality rock), the cost of production that will be incurred in offshore mining, and transportation cost.*

2.4.6 Taiwan, Philippines, and South Korea

TABLE 28. IMPORTS OF PHOSPHATE ROCK BY TAIWAN, PHILIPPINES, AND SOUTH KOREA, 1000 METRIC TONS AND 1000 U.S. DOLLARS

1966

From:		To: Taiwan	Philippines	South Korea
Morocco;	tons	46	0	0
	dollars	1,074	0	0
U.S.;	tons	0	46	12
	dollars	0	349	270

1967

From:		To: Taiwan	Philippines	South Korea
Morocco;	tons	13	0	0
	dollars	504	0	0
U.S.;	tons	0	109	43
	dollars	0	1,907	992

Source: Foreign Trade Statistics of Asia and the Pacific, UN, Vol. IX, Series A, Vol. I.

*See 8.1 for discussion of transportation cost.

TABLE 29. IMPORTS OF PHOSPHATE ROCK AS CALCULATED FROM STATISTICS OF MAJOR EXPORTERS TO TAIWAN, PHILIPPINES, AND SOUTH KOREA, 1000 SHORT TONS

To:	1968	1969	1970	1971	1972	1973	1974
Philippines							
From:							
U.S.	150	183	113	174	126	173	154
Israel	0	0	0	0	4	0	0
To:							
South Korea							
From:							
U.S.	495	604	537	573	574	622	533
Jordan	0	0	0	0	0	11	11
Nauru	0	0	0	0	0	25	108
TOTAL	495	604	537	573	574	658	652
To:							
Taiwan							
From:							
U.S.	0	78	132	107	82	93	62
Morocco	134	89	0	19	24	24	25
Israel	0	0	0	0	10	0	60
Jordan	0	14	11	22	53	89	108
Nauru	0	0	0	0	0	13	39
TOTAL	134	181	143	148	169	219	294

Source: Blue and Torries, loc. cit.

It is clear that these three countries do not have a market potential comparable to the Japanese market. However, their total identified demand in 1974 (from Table 29) of 1.1 million short tons of rock is certainly worthy of attention, especially when compared to the estimated two million ton potential market in the first region that was considered. In addition to their favorable location vis-à-vis southern California offshore producers, the annual rate of growth in their phosphate rock imports since 1968 is 5.9 per cent and this exceeds that of many other market areas.

Before this section on exports is concluded, it should again be stressed that the analysis has concerned itself only with the market for phosphate rock. Clearly this is much less than that for total phosphate materials or total P_2O_5 content for certain markets. This is particularly so for this last market area which imported well over 340,000 short tons of chemical phosphoric fertilizer in 1966 and a similar quantity in 1967. (34) It is interesting, however, that Japan imports an insignificant quantity of chemical phosphoric fertilizer (according to the United Nations statistics) but instead processes the imported rock. (35) Some of the final products are then exported. This, therefore, partly explains the large quantities of rock imported by Japan.

2.5 Phosphate Rock Prices

This section integrates the previous sections in this chapter, providing the necessary supply and demand considerations which must underlie any price analysis. The prime concern is with phosphate rock prices, but the derivative products will also be discussed briefly. The price developments in 1974 and 1975, in particular, brought considerable attention to what had long been an extremely low value product per unit weight when compared to most other minerals. In the 1960's and up to 1973-74, phosphate rock was not much more costly than sand and gravel and the anticipated high cost of offshore mining did not make southern California phosphorite deposits very attractive. (36) Table 30 illustrates these price developments.

TABLE 30. AVERAGE SELLING PRICE PER TON OF OCCIDENTAL PETROLEUM CORPORATION ROCK IN FLORIDA (F.O.B. MINE)

1970	1971	1972	1973	1974	1975
\$4.83	\$4.44	\$4.91	\$6.15	\$17.63	\$39.63

Source: Blue and Torries, op. cit., p. 760.0004M. See footnote (7).

The prices of phosphate rock would be expected to be rather closely related to the BPL or P_2O_5 content, but it should be remembered that one is not dealing with homogeneous products. Numerous other important characteristics of the rock must be considered before any idea of a product price can be obtained. (37) In fact, recent price developments have led to a severe deterioration in the physical characteristics of many rock supplies. (38) This has been caused by high grading when, in certain areas, two shovels of high grade and one shovel of low grade are mined and marketed as high-grade ore. This has resulted, in one particular instance, in a lowering to around 30-31 per cent P_2O_5 of the rock which was previously marketed as 34-35 per cent P_2O_5. (39) It seems reasonable to assume that the tremendous price increases have caused much of this behavior as firms attempt to take advantage of the high prices. However, it has caused buyers to become more sophisticated and to pay more attention to specification of grade and composition, and the increased supplies have had the expected result of causing a severe contraction in prices. Before looking further into the causes of these recent price fluctuations, however, we will illustrate how U.S. list prices for Florida rock have varied with the grade of P_2O_5.

TABLE 31. U.S. LIST PRICES FOR FLORIDA PHOSPHATE ROCK BY GRADE CLASSIFICATION, OF P_2O_5, DOLLARS PER SHORT TONS

	30.2-31.1%	31.1-32.1%	32.1-33%	33.9-34.4%	≥ 34.8%
1960	5.30	5.65	6.23	7.13	8.02
1961	4.99	5.85	6.43	7.33	8.22
1962	5.14	6.00	6.56	7.48	8.37
1963	5.39	6.25	6.83	7.73	8.62
1964	5.84	6.76	7.38	8.34	9.30
1965	6.25	7.23	7.90	8.96	9.95
1966	6.50	7.50	8.15	9.20	10.20
1967	"	"	"	"	"
1968	"	"	"	"	"
1969	"	"	"	"	"
1970	"	"	"	"	"
1971	"	"	"	"	"

Table 31 (continued)

	30.2-31.1%	31.1-32.1%	32.1-33%	33.9-34.4%	$\geq$ 34.8%
1972	6.50	7.50	8.15	9.20	10.20
1973	6.50	5.84-7.50	6.50-8.15	7.55-9.20	10.20
1974	9.00	10.00	10.50	13.00	16.00
1975	31.00	35.50	40.00	47.00	52.00

Source: Blue and Torries, op. cit., p. 760.0006S. See footnote (7).

As can be seen from Table 31, the price of the lowest grade is about 60 per cent of that of the highest grade classification, and a 14.9 per cent increase in P_2O_5 content results in a 67.7 per cent increase in price. This might be due to the narrow range of P_2O_5 levels for marketable rock, the higher cost of beneficiation to obtain a higher grade rock, and the greater-than-proportional increase in value of rock with higher P_2O_5 level as it can now be utilized for more valuable end products.

Another striking feature of Table 31 is the extended period in which published prices within each grade classification did not increase. The reason for the price stability can be deduced from Table 13. This shows that U.S. consumption, while increasing by 47.75 per cent from 1964 to 1966, remained almost constant in the years 1966-74. In 1972 and 1973 consumption finally increased 6.2 and 5.7 per cent, respectively. United States exports showed a sizable 17 per cent annual rate of growth up to 1968, but thereafter increased at the considerably smaller rate of 2.8 per cent up to 1973. A reflection of these developments can be seen in the excess of domestic mine production over consumption. This increased from 7183 short tons in 1964 to 15,915 short tons in 1968, the year of peak export volume, and thereafter decreased to 10,904 short tons of phosphate rock in 1973.

The spectacular price developments in 1974 and 1975, however, must be associated with the "world leadership in pricing phosphate rock" which Morocco assumed on January 1, 1974. (40) Referring to Tables 4, 5, and 6, it is clear that Morocco was the obvious candidate among the three principal producer-nations to lead such a development. Its commanding position in the large Western European market as well as its 12.3 per cent annual rate of growth of its total exports from 1970 to 1973--more than twice that of either the U.S. or U.S.S.R.--made it a natural price leader. Under these supply-demand and market-structure conditions, prices increased.

From $14 a ton at the end of 1973, the price of 75 per cent BPL was set at $42 a metric ton F.A.S., an increase of exactly 200 per cent. The prices of rock did not stop there and it is reported that high-grade rock from the former Spanish Sahara sold as high as $80 a ton and Moroccan rock at $68. (41) These were exceptional cases, however, and the export prices of U.S. rock (presented in Table 32) did not quite reach this level. This study has not undertaken a definitive analysis of supply and demand in the international markets or the pricing policies which are pursued there. The implication of the statements made above, however, is that Morocco has a sufficient market share to give it a substantial influence on prices and quantity of phosphate rock, especially in Western Europe. When this condition is combined with a cooperative stand by export cartels of other countries, it is clear that "competitive markets," in the sense that economists use this term, no longer exist.

TABLE 32. PHOSPHATE ROCK EXPORT ASSOCIATION PRICES FOR U.S. PHOSPHATE ROCK EXPORTS[c], DOLLARS PER SHORT TON

	66% BPL	68% BPL	70% BPL	72% BPL	75% BPL	77% BPL
1971, July 1	6.58	6.88	7.52	8.05	9.09	10.07
1972, July 1	7.47	7.77	8.41	8.95	9.98	10.96
1973, March 1	8.39	8.84	9.64	10.27	11.70	12.95
1974, January 1	16.07	17.86	19.64	21.43	24.55	26.78
July 1	24.55	26.79	29.47	32.14	37.50	42.41
October 1 (effective January 1, 1975)	32.66	35.38	39.01	43.55	49.90	56.25

c. Price bases are run of mine, dried, unground, bulk, f.o.b. vessel, Tampa-range or Jacksonville, Florida. Unpublished increases on new business, as of July, 1975, and all business, as of January, 1976, are not believed to be implemented.

Source: Blue and Torries, *op. cit.*, p. 760.0007B. See footnote (7).

The Phosphate Rock Export Association and the Phosphate Chemicals Exports Association are organizations which handle all exports of phosphate rock and phosphate chemicals for their members. These two export associations are organized under the Webb-Pomerene Act and thus are immune from U.S. antitrust prosecution. In this way, U.S. phosphate rock exporting firms can coordinate their overseas marketing strategy.

These high rock prices have resulted in even more extraordinary price increases for fertilizer products, and it is reported that diammonium phosphate prices rose from the high 40's to about $170/ton domestically and to \$400 overseas. (42) Prices then declined to around \$130 in the U.S. in 1975 and are now quoted from \$105 to \$115. The reaction of buyers in 1975, the decrease in market supply associated with the much higher prices, in addition to a worldwide reduction in real income, caused a 20 per cent decrease in the quantity of phosphate fertilizers sold. The expected price cutting by various suppliers reportedly caused a "growing panic" in Morocco. (43)

Unless a cartel is established by the major producers, one can expect the prices of phosphate rock to decrease slowly but surely. This is likely to take place despite renewed growth in real income and a resultant recovery in the demand for phosphate rock; however, with such renewed growth and recovery in demand, this price reduction will be smaller than it would be without these developments.

2.6 Price Elasticities of Demand and Supply

This study could not undertake a thorough statistical demand analysis for phosphate rock, since this would be a major project in itself. But this section on prices should not be concluded without referring to an older study which deals with elasticities in some detail.

The price elasticity of demand or supply is basically a somewhat sophisticated name for a rather simple idea. The concept attempts to come to grips with the relationship between price and quantity of any commodity of interest. (44) Elasticity measures the percentage change in quantity resulting from a one per cent change in price. The price elasticity of demand or supply is elastic if the ratio of the percentage change in quantity to the percentage change in price exceeds one; unitary elastic if it equals one, and inelastic if it is less than one. In A Statistical Analysis of U.S. Demand for Phosphate Rock, Potash, and Nitrogen (45) Hee attempts to quantify the effects of price, consumer income, and level of technology on the demand for these raw materials. His data obviously do not capture the price developments in the 70's, but it is still of interest to consider the elasticities which he calculated for phosphate rock. For the four market classifications--aggregate domestic, agricultural, industrial, and export--Hee obtained 0.29, 0.27, 0.79, and 2.88, respectively. This shows aggregate domestic and agricultural demand to be relatively inelastic, with a one per cent change (increase) in price resulting in a less than 0.3 per cent change (decline). Industrial demand is found to be somewhat less inelastic in quantity demanded (closer to unit-elastic), while export demand is highly elastic.

Confirmation of the fairly inelastic demand elasticities of these first three classifications, especially agriculture, certainly should come as no surprise. The inability of other materials to take the place of phosphates in fertilizers, etc., is well known. The high estimate for export price elasticity is also to be expected in that fairly good substitutes exist for U.S. supplies on the world market. But even though export prices of U.S. phosphate rock have increased considerably, as described, one cannot use the above elasticity to project how U.S. exports of rock will change accordingly. This is because of the assumption of ceteris paribus which must hold when using the elasticity measure.

The prices of all exporters have risen by about the same percentage, and the impact will therefore be substantially less than it would have been if the U.S. suppliers had been the only ones to raise their prices.

No estimates of supply elasticity have been found, but it is clear that supply is not highly elastic. One would expect a substantial time lag from initial price developments and a resultant change in output of phosphate rock from brand-new mines or processing facilities. This is due to the fact that new production capacity requires several years to be installed and become operable. In recent years a substantial excess capacity has existed, however, so that the speed of adjustment to a given outward shift in demand (and a resulting higher price) could be relatively short. Table 11 shows how capacity and marketable production have varied since 1970 and how they are expected to change up to 1980. Undoubtedly, much of the change evidenced in this table for 1974 and 1975 has been in response to the high phosphate rock prices in these years. Likewise, it is reasonable to assume that these recent increases in the price of phosphate rock will encourage those who have given serious consideration to mining southern California phosphorite deposits. They should not be overly confident that these high prices will last, however. The few early signs that have been registered indicate that these markets might become less attractive in the near future. Also, should these offshore producers penetrate any market on a large scale, this will likely cause some reduction in the prevailing prices as specific markets adjust to supply increases.

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(2) For a description of various aspects of phosphate mining in North Carolina, see Legal Aspects of Phosphate Mining in North Carolina, by Michael A. Almond, Sea Grant Publication UNC-SG-75-05, February, 1975.

(3) 1975 Fertilizer Situation, Economic Research Service, U.S. Department of Agriculture, December, 1974.

(4) Ibid., p. 5.

(5) Ibid.

(6) Chemical Markets, The Journal of Commerce, May 6, 1976.

(7) Personal communication from Dr. James Lehr, TRA, 5/11/76. Italian and Greek plants using Tunisian rock have found serious foaming problems, at times reducing the reactor space to such an extent that plant output dropped to 20 per cent of designed capacity.

(8) This might well seem to be an arbitrary assumption but it will simplify the analysis considerably and it is also closely aligned to the approach taken by other studies. In particular, see "An Economic Evaluation of Markets for California Phosphorite Deposits," by George C. Sweeney, Jr. and James W. Bradley, A. D. Little, Inc., 1963.

References and Footnotes to Chapter 2 (continued)

(9) Final Environment Impact Report, Cuyama Phosphate Mine, Santa Barbara County, Calif., Henningson, Durham and Richardson, December 3, 1974. Neocene Phosphate Faces in California, Ph.D. dissertation by Paul Dickets, Stanford University, 1970.

(10) "Mineral Resources Development in the Public Domain; An Unfinished Case History," by Richard C. Runvik, Staff Manager - Geology, U.S. Gypsum Company, Chicago, Illinois, paper presented at the Eighth Forum on Geology of Industrial Minerals, Iowa City, Iowa, April 13, 1972.

(11) A personal interview with a representative of Global Marine on September 17, 1975, revealed a very pessimistic view of what various government regulations and pressures from conservation groups could do to a project of the kind considered here.

(12) Final Environmental Report, HDR, op. cit., pp. 32-33.

(13) Personal communication from F. C. Appleyard, Director, Mining and Exploration, U.S. Gypsum, July 15, 1975.

(14) Personal communication from Al Roberts, U.S. Geological Survey, May 26, 1975.

(15) Blue and Torries, op. cit., p. 760.0008I.

(16) Marine Phosphate Deposits Offshore Baja California; report prepared for Minerales Submarinos Mexicanos, S.A., by R. W. McComas, May, 1967, and made available for our study by Mr. Henry Wheless, Vice President, Economic Development, Valley Nitrogen Producers, Inc., Fresno, California.

References and Footnotes to Chapter 2 (continued)

(17) Ibid., p. 2.

(18) Journal of Commerce, p. 6A, November 24, 1975.

(19) Blue and Torries, op. cit., p. 760.0008K.

(20) Journal of Commerce, p. 8A, November 17, 1975.

(21) Character and Origin of Marine Phosphorites, M.S. thesis by David W. Pasho, University of Southern California, June, 1973.

(22) Blue and Torries, op. cit., p. 760.0006G.

(23) Total apparent domestic consumption = Sold or used by producers + Imports - Exports. A and B are different because (a) B excludes direct application fertilizer rock, and (b) B is not quite in phase time-wise with A. For full details, see Blue and Torries, op. cit., p. 760.0006D and E.

(24) Many of the statistics used throughout this section have been extracted from various sections of the SRI Phosphate Rock Report. Specific references will be given throughout the section.

(25) Overall, M. P., "Mining Phosphorite from the Sea," Ocean Industry, September, 1968, p. 45.

(26) Sweeney, George C., and James W. Bradley (1963), ibid., p. 161 [see (8)].

(27) Personal communication, 5/6/76, by Mr. R. Henry Wheless, Vice President, Economic Development, Valley Nitrogen Producers, Inc.

(28) Blue and Torries, op. cit., p. 760.0001B.

References and Footnotes to Chapter 2 (continued)

(29) Manderson, M. C., Fig. 1. "Commercial Development of Offshore Marine Phosphates," Paper No. 1658, Offshore Technology Conference, 1972.

(30) Overall, _op_. _cit_., p. 45.

(31) _Foreign Trade Statistics of Asia and the Pacific_, 1970, UN, Volume IX, Series A, No. 1.

(32) _Yearbook_, Australia, 1973, No. 59, Bureau of Statistics.

(33) Blue and Torries, _op_. _cit_., p. 760.0009S, and the _Christian Science Monitor_, May 27, 1976, p. 12.

(34) _Foreign Trade Statistics of Asia and the Pacific_, S.I.T.C. 561.2.

(35) According to _World Trade Annual_, 1972, prepared by the Statistical Office of the United Nations, Vol. II, Japan imported slightly over 14,000 short tons of chemical phosphoric fertilizers in 1972.

(36) Sorensen, Philip E., and Walter J. Mead, "A New Economic Appraisal of Marine Phosphorite Deposits off the Southern California Coast."

(37) Lehr, James R., and Guerry H. McClellan, "Phosphate Rock - Important Factors in Their Economic and Technical Evaluation," _The Mining and Beneficiation of Fertilizer Minerals, Mining and Beneficiation of Phosphates_.

(38) Personal communication by Dr. James Lehr, TVA, 5/11/76.

(39) _Ibid_.

(40) _1975 Fertilizer Situation_, Economic Research Science, U.S. Department of Agriculture, p. 16.

(41) _The Economist_, August 9, 1975, p. 65.

References and Footnotes to Chapter 2 (continued)

(42) "High Costs Seen Block to Fertilizer Expansion," Journal of Commerce, September 29, 1975.

(43) The Economist, loc. cit.

(44) The price elasticity of demand (or supply) is usually denoted by η and defined as:

$$\frac{-dQ/Q}{dP/_{p}}$$; i.e., one is basically interested

in how price changes affect the quantity demanded (or supplied) or how the quantity affects the price. The elasticity can be derived and defined in this way:

$$\frac{d[TR]}{dQ} \equiv \frac{d[P.Q]}{dQ} \equiv P + Q\,\frac{dP}{dQ} \gtrless 0$$

or :
$$\frac{d[TR]}{dQ} = P[1 + \frac{Q}{P}\,\frac{dP}{dQ}] \gtrless 0$$

$$= P[1 - \frac{1}{\eta}] \gtrless 0$$

where TR $\equiv$ total revenue

Therefore, if

(*i*) $\eta = 1$, then $d[TR]/dQ = 0$; this indicates that if $\eta = 1$ no change is made to the total revenue as quantity is changed (this holds equally if we concentrate on price).

(*ii*) $\eta > 1$, then it becomes apparent that $d[TR]/dQ > 0$ (assuming $P > 0$) and now the total revenue increases as quantity increases.

(*iii*) $\eta < 1$, then $dTR/dQ < 0$ and the total revenue decreases as quantity increases.

References and Footnotes to Chapter 2 (continued)

These three cases are defined as describing unitary, elastic, and inelastic demand.

(45) Hee, Olman, A Statistical Analysis of U.S. Demand for Phosphate Rock, Potash, and Nitrogen, Division of Mineral Economics, Bureau of Mines, U.S. Department of the Interior, 1969.

3. OFFSHORE PHOSPHORITE MINING EXPERIENCE

With those readers in mind who have little or no familiarity with offshore developments, this chapter is provided to summarize historical developments as well as to evaluate them from our vantage point in time.

The most publicized and possibly the most serious attempt to initiate offshore phosphorite mining in the United States was made by Collier Carbon and Chemical Company, a subsidiary of Union Oil Company, during the period 1962-63. The reason for Collier's effort was simply to obtain a cheaper input of phosphate for its processing plant and in so doing achieve a higher rate of return than that of comparable investments. According to Mr. Homer Reed, Collier's Vice-President for Research and Development at the time, the cost of delivered rock to its plant would be somewhere above $8. This would certainly have represented a significant reduction from the prevailing price of about $15 per ton of rock delivered to the plant from Wyoming. (1) Mr. Reed's estimates were less optimistic than those provided by Mero, who estimated a total cost of production at about $4 per ton plus about $1.50 to move the rock produced offshore to the California market. These amounts were based on the assumption of a $3 million dredging rig and an annual production of at least 500,000 tons. (2)

Despite this seemingly great profit potential for the phosphorite deposits located in the 30,240 acres which Collier leased from the Federal Government in December, 1961, the project was aborted and the lease bonus repaid when Collier charged that the submerged land "was not clear and minable as stated under the leasing terms, inasmuch as unexploded naval shells were encountered by the company in its dredging operations for the recovery of nodule samples." (3)

Even though Collier was required to stop dredging in the area by the U.S. Navy after the shells were discovered, it also was the case that the "quality and quantity of nodules dredged were 'disappointing' and that dredging in (a marine) environment was more difficult than was assumed in any of the known project studies." (4) Thus, one can easily speculate whether the new information about the economic potential of the area after the lease had been awarded was more important in stopping the project than the actual presence of unexploded shells. Even though Collier was not permitted to resume production until a determination had been made that no accidental explosions could occur, it is clear that the Company would have pressured for a speedy resolution of this problem if a profitable operation had been expected. A spokesman for Union Oil has recently confirmed that no research is presently being done with regard to phosphorite mining and there is no longer any involvement in this area.

Another known attempt to initiate commercial mining of southern California phosphorites was made by Lockheed Aircraft Corporation and the International Minerals and Chemical Corporation (IMC) in the early 1960's. A joint exploration program was undertaken and the areas of interest were those of the 30 Mile Bank west of San Diego. The combination of forces involving Lockheed and IMC would appear to have major advantages due to the former's strength in engineering skills and sciences in particular, and the latter's position as the No. 1 U.S. phosphate rock producer, mining 25 per cent of the total U.S. output. (5) Also, IMC was, and is, a fully integrated processor of rock and seller of end products in domestic and foreign markets. It is reported that a major factor in the abortion of the joint effort was the lack of reliable nodule sampling technology from which to derive the engineering parameters essential to the design or costing of a nodule recovery system. (6) If, however, the expected rate of return from this type of investment would come close to 36 per cent return on sales and 58 per cent return on equity, as reported in Lockheed's own internal report (7), it is clear that abortion of the project implies either the estimates were wrong or non-profitability factors were responsible. Some of these factors will be given attention throughout the remainder of this report.

Another known involvement in exploration and economic evaluation of offshore phosphorite mining by a U.S. company is that already dealt with in a previous chapter which involves Global Marine, Inc., and the Baja California deposits. Available information indicates that this is one of the offshore phosphorite mining projects which various private firms consider to have great potential. The conversations with a representative of Global Marine, reported earlier, indicated the desire and willingness to start operations. Recent conversations with Mr. R. W. McComas, who has been a major participant in the Baja California evaluations, indicated that preliminary work is still being done on these deposits.

With respect to U.S. deposits, however, Mero and his associates have great confidence in the economic potential of the southern California deposits. No detailed, recent reports or evaluations on possible exploitation are available, but their dredging and barge transportation costs are reported to be about $1 per ton of phosphorites. (8) At this dredging cost, phosphorite mining is most likely to be profitable (refer to operating costs of technology II in this report and resulting internal rates of return in Table 45). If a lease could be obtained from the Department of the Interior at competitive conditions (refer to Section 8.4.1 for a more detailed discussion of leasing policies), it is likely that Mero's group would initiate commercial exploitation of southern California phosphorite deposits.

The marine deposits of Chatham Rise in New Zealand, containing an estimated 100 million tons of phosphorite nodules with an average phosphate content of 21.5 per cent (9), are also being evaluated for possible commercial exploitation. JBL Minerals, Ltd.,is reported to be forming a mining consortium, but attempts to determine the extent of work already done have not been successful.

Even though these are the only known efforts where serious evaluations of offshore phosphorite mining have been, or are being, undertaken, this is unlikely to be fully representative of the actual work being done by firms here and abroad. It is clear that a firm's optimum strategy in its efforts to maximize expected rates of return is not always to publicize its research efforts. In the area of ocean mining, however, there have been a large number of joint ventures with considerable publicity about their intended activities. Thus, the information available from numerous publications and personal communications might be reasonably representative.

Before concluding this short summary of past and present activities in offshore phosphate mining it should be pointed out that most of the publicity in ocean mining related to manganese nodules often has little or no relation to, or value for, phosphorite mining. The nature of the mining technology and the deposit characteristics of manganese nodules are sufficiently different from those of phosphorite to make simple and fast analogies dangerous.

References and Footnotes to Chapter 3

(1) Business Week, June 30, 1962, p. 146.

(2) Ibid.

(3) Elkins, Clifford, and B. Miller Sprangler, The Potential for Marine Mining of Phosphates and Some Implications for Federal Policies and Programs, National Planning Association, December 20, 1967. p. 14.

(4) Sorensen, Philip E., and J. Walter Mead, "A New Economic Appraisal of Marine Phosphorite Deposits off the California Coast," Marine Technology Society, The Decade Ahead, 1970-80, p. 495.

(5) Dunn, M. W., Ocean Mining, A Summary Report on the Business Potential of Marine Mining, Product Development Department, Lockheed Aircraft International, Los Angeles, California, September 20, 1963.

(6) Elkins and Sprangler, op. cit., p. 15.

(7) Dunn, M. W., loc. cit.

(8) Personal communication from Mero, 1976.

(9) "Resources from the Seabed," New Zealand Science Review, 32(3), 55 (1975).

4. MARINE MINING TECHNOLOGY CONSIDERATIONS

4.1 Introduction, Objective, and Approach

It would clearly be unwise in this report to make mining cost calculations for each of the main technologies which could be utilized in phosphorite mining. A reference made to a technology pertains to a specific mining system, yet is sufficiently general so as not to require details that are not available. As examples of what are referred to as technologies, this chapter will be concerned with the following: 1) clamshell, 2) bucketline, 3) continuous bucketline (CBL), 4) dragline, and 5) hydraulic suction technologies. A brief discussion is given of each in order to give the reader a better perspective of the available production systems. We will also explain why this report chose hydraulic suction dredging as the underlying production system.

A caveat should be given concerning any inference about the superiority of this particular choice of technology as opposed to alternative technologies. No such superiority is claimed. The conclusions that will be drawn when discussing a mining process will hold only for that particular technology and nothing should be inferred regarding other production systems. In the final analysis, the eventual rate of return on investment should be the criteria for determining the most suitable technology. However, since it is not known what the rates of return are for other production systems, one should not infer any claim of superiority of the chosen technology on the basis of this study alone.

Another point to be made at this stage concerns the generality or level of detail of subsequent discussions. This study is an economic analysis based on currently available engineering data; it updates a prior analysis based on less favorable market conditions and even more primitive engineering data. No expertise in marine engineering is claimed and the available information on the technologies to be dealt with comes from publications and from personal communication with industry sources. It is likely, therefore, that these discussions will be lacking in detail from the point of view of marine engineers, in particular. It is felt, however, that a lack of complete and perfect information should not be a deterrent to providing an economic analysis. As further data become available, the analysis may be refined.

The industry sources which we have contacted generally agree with this assessment of engineering information but emphasize that more detailed engineering feasibility studies must be undertaken before one can have a high degree of confidence in the conclusions. This view seems incontrovertible. Since this analysis will be built around some rather specific and fairly restrictive assumptions, one major purpose of a detailed engineering feasibility study will be to see which of these assumptions must be relaxed, and to what extent, in any particular mining venture. An attempt will be made to indicate the sensitivity of the technologies discussed to some of the important engineering parameters, but one should not expect these discussions to be exhaustive. An introduction to some of the major technologies that have been discussed in the literature of marine mining will now be presented.

4.2 Clamshell Dredging

This production system goes back farther in time than the other four to be considered. This is undoubtedly because of its being less complex than the others. In its simplest form it consists of a clamshell or a grab dredge, suspended from wires or ropes and is best suited for medium hard to loose granular material. Capacities of the clamshell are reported by Cruickshank, Ramanowitz, and Overall (1) to be up to 220 cubic yards.

The sizes and complexities of clamshells in operation vary considerably according to the nature of the material mined and the deposit characteristics. Apparently their greatest use is in dredging sand and gravel, but as long as the material is unconsolidated a clamshell dredge can be used. For high efficiency, the material dredged and the conditions at the dredge site should be such as to allow the dredge to be periodically stationary and dig into the same pit to recover full-capacity loads. This requirement could be fulfilled with a sizable deposit of good thickness and appropriate composition. Or it could be met where water movement would be such as to move the material into one pit, thus allowing the dredge to remain stationary and operate at capacity. Neither condition applies to marine phosphorite deposits. Therefore, it is unlikely that this type of dredging system could operate efficiently in phosphorite mining. Even though indications are that some areas exist where the depth of phosphate material is adequate for the operation of a clamshell dredge, this is not generally the case. For the single layer of nodules assumed in most previous studies it is quite clear that a clamshell technology would not be efficient.

As for dredging cost per unit of material, on the basis of sketchy evidence, the clamshell does not compare favorably with other systems. This, of course, will vary from use to use, but a comparison between the use of a clamshell and that of a bucketline dredge for tin mining in Thailand finds the latter less costly in offshore mining. (2) One should not draw firm general conclusions from this evidence, since the example given is quite old (1962) and since the cost of clamshell dredging is likely to vary considerably as the mining parameters change. The only point made here is that the clamshell apparently is not always the least-cost production system per unit of output.

4.3 Bucketline Dredging

This technology consists in the operation of a series of steel buckets which are mounted on an extended ladder or arm. The mining capacity of this type of technology clearly depends on the same parameters that have been discussed previously. The annual capacity of a 24-cubic-foot bucket system discussed by Romanowitz (3) reached 10 million yards. However, plans for a "54 cubic foot capacity fixed-arm mining dredge capable of digging to approximately 150 feet below sea level" were apparently under way at the terminated Marine Minerals Technology Center (Department of Commerce, National Oceanographic and Atmospheric Administration) at Tiburon, California, but the fate of this project is unknown. (4)

This type of technology has been assumed in one study on phosphorites (5), but from the information now available it is not a viable production system for the greater water depths that must be dealt with. The digging depth of a bucket ladder cannot easily exceed 200 feet and, at the present stage of technology, the weight of the ladder and buckets does not permit a simple projection of the existing systems to one that might operate at 750 feet and more. (6) Finally, it is probable that the nature of shallow deposits is unsuitable for either the bucketline or the clamshell technology.

4.4 Continuous Bucketline Dredging

This technology has received most attention due to its potential use in manganese nodule mining. In 1970 the system was tested at a depth of 3755 meters. Simply described, it consists of a huge loop (8400 meters of polypropylene-braided cable, in the case cited) with smaller loops having buckets placed at every 25 meters along the length of the cable. As the loop circulates continuously through the system, the weights and the buckets are removed at the forward drive and put back on the line at the stern. (7)

According to Masuda, Cruickshank and Mero, "there were no mechanical problems and the recovery of many nodule-sized shells indicated a high potential for the operation of the bucketline in a nodule area and for its further development to a deep water automated system." (8) Despite the various advantages of such a system over an hydraulic technology (due to easier handling of rope than of pipes, as well as higher general efficiency and considerably lower cost), it is clear that this system has been designed for ocean mining at considerably greater depth than that of the phosphorite deposits on the Continental Shelf. One would think that fairly simple modifications could be made to these deep-sea manganese nodule production systems for application to a phosphorite mining operation, but this type of inference is very dangerous and can lead to serious problems. Not only are the environmental characteristics of manganese nodule mining projects quite different from those that must be considered here, but it is also likely that manganese nodule mining will be on a larger economic scale than phosphorite mining. Presently it is improbable that the economics of the latter will be able to support the high-cost technology developed for manganese nodules. As a way of illustrating this point, the analogy was given that using manganese nodule mining technology for phosphorite mining would be "like utilizing a Boeing 747 for crop dusting." (9) It should also be stated, however, that only economic and engineering feasibility studies and evaluations can determine what types of technologies a phosphorite mining operation could support.

4.5 Dragline Dredging

As already indicated, this is the technology that has been given most attention and analysis in connection with phosphorite mining. For details of this particular production system the reader should consult publications by Mero. Simply stated, the dragline technology consists in the operation of a dredge bucket which is pulled along the seafloor. This picks up whatever lies in its path and is subsequently pulled to the surface and emptied on a dredge barge.

The main attractions of this method are simplicity and low capital cost. But for a properly functioning mining system a great deal of detail is needed. Although possibly outdated, by virtue of being 17 years old, an examination of Mero's Ph.D. thesis will provide some insight into the details needed for this kind of analysis. (10) This type of technology has not been tested beyond a pilot project basis. Smaller draglines have been utilized under various sampling operations; it is possible that these could be considered as pilot operations indicating how a full-scale production system would operate.

4.6 Hydraulic Suction Dredging

This is the type of mining system on which this study will base its evaluations. Clearly, a fairly detailed description of assumed technology must be part of the evaluation and this will follow in a separate chapter. In these introductory remarks, however, it should be noted that the basic technology is well defined and tested in offshore dredging.

In South West Africa diamondiferous gravels have been recovered from the sea bed by using hydraulic suction in conjunction with high-pressure water jets to disintegrate compacted sediments. (11) This system has also been used for dredging in Thailand, as well as for sand and gravel dredging in Great Britain and elsewhere. (12)

It must be admitted, however, that these mining operations are probably not sufficiently similar to any future phosphorite hydraulic suction mining project and one should, therefore, be cautious in making extrapolations. Evidence of the application of this technology to deeper waters is provided, however, by dredging done by Deepsea Ventures, Inc., at 18,000 feet. (13) Information which has been received from industry sources indicates that no technological barriers exist to application of this technology to phosphorite mining. The final deciding factor, therefore, is economic return.

References and Footnotes to Chapter 4

(1) Cruickshank, Michael J., Charles M. Romanowitz, and M. P. Overall, "Offshore Mining - Present and Future," Engineering Mining Journal, January, 1968, Fig. 7.

(2) Idem, ibid., Table 4, p. 4.

(3) Romanowitz, C. M., "Onshore Alluvial Mining Results as a Guide to Future Offshore Mining," World Mining, February/March, 1971.

(4) Personal communication from Michael J. Cruickshank, November, 1975.

(5) Sorensen, Philip E., and Walter J. Mead, "A New Economic Appraisal of Marine Phosphorite Deposits off the California Coast," Marine Technology Society, The Decade Ahead, 1970-80.

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(8) Idem, ibid., p. J-839.

(9) Personal communication from Michael J. Cruickshank, September 2, 1975.

(10) Mero, John, An Economic Analysis of Mining Deepsea Phosphorites, Ph.D. Dissertation, UC-Berkeley, 1959.

(11) Cruickshank, Michael J., Mining and Mineral Recovery, UST Handbook/Directory, 1973, p. A/22.

(12) Hess, H. D., 1971, Marine Sand and Gravel Mining Industry of the United Kingdom, NOAA Technical Report ERL 213-MMTC 1, U.S. Govt. Printing Office, Washington, D. C.

References and Footnotes to Chapter 4 (continued)

(13) Pings, W. B., and Donald A. Paist, "Minerals from the Ocean, Part II," Mineral Industries Bulletin, May, 1970.

5. ECONOMIC CONSIDERATIONS OF THE SOUTHERN CALIFORNIA PHOSPHORITE DEPOSITS

5.1 Purpose and Outline

Before proceeding with a description of the proposed dredging technologies and an analysis of the associated costs, some of the characteristics of the deposits and the nodules will be discussed. Fisher and Richmond have presented the available data on deposit and nodule characteristics in a companion study. A brief review of some of these data within an economic context will be presented here. The purpose is to point out the more important economic factors to be taken into consideration when evaluating the commercial potential of marine phosphorites.

5.2 Deposit Characteristics

This study assumes that a substantial exploration program would be undertaken prior to any commercial exploitation. This program must continue and expand the sampling activities that have already been undertaken so as to delineate the deposits of economic interest. The importance of such an exploration program is realized when the cost of transporting and processing nonphosphatic material is evaluated. In subsequent chapters in which the costs of dredging, transporting, unloading, and beneficiation are considered, the effect of a high "dilution ratio" on costs of production will be made apparent. This ratio indicates the extent that nonphosphatic, foreign or debris type material are interspersed among the high-phosphate nodules. If the ratio happens to be, say, 1/2 instead of zero, there will be a doubling of the dredging cost per ton of high,phosphate material. The cost of barge transportation to the processing plant located onshore is similarly affected. Finally, when beneficiation takes place and the nodules must be crushed, a high dilution ratio will yield large quantities of finely crushed nonphosphatic material. This is based on the postulates that (1) capital equipment cannot separate the debris from the high-phosphate nodules; (2) it would be too costly to employ workers to do this by hand; and (3) the crushing must be carried out to about 200 mesh. Cost considerations in the following chapters will indicate how operating costs at the different stages of production are likely to be affected by various dilution ratios.

Even when much more complete information is available regarding the characteristics of deposits, their great variability--both from one deposit to another and within each depost--will result in higher costs of production than if there were greater uniformity. The extent of this cost will depend on the nature of the technology used and on which particular areas a company will have to exploit in order to reach full capacity utilization.

The bathymetry figures show that the depth range among deposits is 4 meters to 700 meters. Within deposits, the average depth varies from 75-400 meters. This clearly indicates that an operator must be equipped to deal with substantially different water depths during dredging operations. In particular, the production technology selected must be able to adjust to various depth conditions. The pumps and motors designed to handle these different water depths will not be used at full capacity at all times. This situation will result in higher operating costs per ton of material than if the range of depths were narrower.

The spatial distribution of the phosphatic material within each deposit is unlikely to be uniform, although the statistics in the Fisher and Richmond report are based on a uniform distribution of 1/3 meter of nodules or 1 meter of phosphate sand within the areas outlined. These simplifying assumptions have been made because the sampling to date has not been sufficient to determine the actual distributions, which are not as uniform as assumed. Certain areas within a deposit may contain little or no phosphatic materials, while others may be highly concentrated in phosphorites. It is not clear whether a uniform, less concentrated distribution would be more favorable to commercial exploitation than a nonuniform, more concentrated distribution. The varied type of deposits would require higher investment in prospecting to delineate the exact spatial sorting of the phosphorite. For a more uniform distribution, the eventual mining costs per ton might actually be greater than if the material were more concentrated.

Total estimated reserves in the eight deposits under consideration* are 63.2 million metric tons of phosphate nodules, or 118.4 million metric tons if Holzman's figures for the Cortez-Tanner Bank (only nodules) are used, and 107.6 million metric tons of phosphate sand. These reserve figures could possibly be raised considerably. The process by which these phosphatic materials were formed extends far back in geological time, so that areas with thicker unconsolidated surficial materials may contain

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*Coronado Bank, Cortez-Tanner Bank, Forty Mile Bank, Lasuen Knoll, Santa Barbara Island High,Santa Monica Bay, San Nicolas Ridge, and Thirty Mile Bank.

large volumes of buried or embedded phosphatic material. For example, using isopack sediment thickness data for Santa Monica Bay and San Nicolas Ridge, and assuming the same percentages for nodules and phosphatic sand occurrence within the Quaternary Fill as within the top 1 meter of surficial sediments, the reserve figures are increased considerably to 272.06 million tons (327.27 million metric tons if Holzman's figures are used for the Cortez-Tanner Bank) and 1.875 billion tons of phosphatic sands. Isopack data are currently being developed for the other deposit areas. This possibility, along with an assumed density of phosphatic material, could raise the figures for "hypothetical reserves" even higher. Only core drilling will be able to determine whether or not these unconsolidated sediments do in fact contain phosphatic materials. Coring will also be necessary to determine the phosphate content of the sediments and the relative distribution of phosphate nodules and sands.

The presence of phosphatic material in the thicker sediments would likely enhance the profitability of a commercial mining venture. A higher rate of production will generally yield lower operating costs per ton (depending on the dredging technology used), as the fixed costs will be charged to a greater number of tons mined. Also, less mobility and, therefore, less variability in dredging conditions will lower operating costs. This results from avoiding costs of down-time required to move to another deposit and of adjustment costs associated with changing dredging conditions.

5.3 Mineral and Chemical Composition of Marine Phosphorites

Before reviewing the potential problems caused by the particular chemical and mineral composition of marine phosphorites, a comment must be made on the nature of the sample data used. The Coronado and the Santa Monica Bay deposits have received by far the most attention, with 28 out of a total of 32 chemical analyses undertaken. This should not be given undue weight. The Coronado Bank has apparently been favored because of background data already available, location and logistics. (1) One is warned about the use of the Coronado Bank data as typical for basing an economic analysis of what other borderline deposits may contain. Furthermore, it is strongly suspected that deposits at Thirty and Forty Mile Bank are superior in quality. (2) Here the term "quality" refers to P_2O_5 content and lack of detrital materials in the nodules. The nodules at Thirty and Forty Mile Bank apparently have a greater part of the limestone, CO_2 and CaO, replaced by P_2O_5 such that the ratio of CaO/P_2O_5 is smaller and, therefore, the nodules are richer in P_2O_5 per unit of ore. On the other hand, many factors other than the purity of the nodules must be considered in the evaluation of a deposit. It is illustrative of these data problems that there are only two chemical analyses for Forty Mile Bank and one for Thirty Mile Bank. In view of these warnings, it is hazardous to draw general conclusions about the chemical and mineral composition of the phosphorites in these deposits. It is, nevertheless, necessary, on the basis of the incomplete data available, to attempt a preliminary evaluation of the chemical quality of phosphate rock derived from these deposits. The criteria used in this evaluation are those discussed by Everhart (3) and by Lehr and McClellan. (4) These "critical limits" or the maximum content with regard to certain chemicals or minerals are not absolute and will vary with the overall economic evaluation. If a deposit has compensating favorable attributes (for example, excellent spatial location relative to markets), the utilization of more costly processing might be justified and the problems will be reduced or eliminated.

The first potential problem related to chemical quality factors concerns the combined iron and aluminum content. This generally should not exceed 2.5 to 4 per cent, depending on end use. If excessive it is troublesome, particularly in wet process acid (WPA) intermediates and their ammoniation products (AP). Iron and aluminum content is "mainly responsible for sludges and postprecipitation in WPA, scale formation in superphosphoric acid (SPA) production, insoluble phosphate compounds in liquid ammonium phosphates (AP), and unwanted agglomeration in nongranular AP products." (5) The existing sample data indicate that the Coronado Bank analyses are not very favorable in their iron and aluminum content. They show an average content of 3.43 per cent. Seven out of 16 samples are within the range 2.5-4.0 per cent, and six are beyond the 4 per cent upper limit. This is indicative of a significant problem that must be given further attention in a more detailed feasibility study. The other deposit for which sample data exist is that of Santa Monica Bay. One sample is within the critical range, while another shows an iron and aluminum content greater than 4 per cent. None of the few samples available from other deposits under current investigation indicates any problems with respect to iron and aluminum content.

Another factor that must be considered is the weight ratio of calcium oxide (CaO) to P_2O_5 content. According to Everhart, this ratio should not exceed 1.6 since the cost of the sulphuric acid consumed in the production of final products then generally becomes prohibitive. Again, the analyses of the Coronado Bay deposit show a high and unfavorable CaO content. Seven of the 16 samples are beyond the critical limit. This is also the case with the Santa Monica Bay and the Forty Mile Bank deposits. Samples from the last two deposits show two out of four and two out of three above the critical limit, respectively, though the latter are close to 1.6. Again, this seems to be a potential problem.

A third critical factor on which few data have been found concerns the content of chlorine in marine phosphorites. This problem has already been dealt with regarding the North African deposits. Generally, a chlorine content exceeding 0.13 per cent leads to processing problems because it corrodes the processing equipment. While this could be avoided by modifying the equipment, this will involve higher capital costs. The tables on chemical analyses in Part 1 of the Fisher and Richmond report contain no information about chlorine, indicating that analysts might not have considered this a significant problem. A chlorine test performed by IMC concluded that the observed chlorine content was insignificant. (6) If crushed nodules or phosphate sand are washed with salt water, however, it is reported that the chlorine content could rise and necessitate further washing in fresh water. (7)

A fourth chemical component that might cause problems is magnesium oxide. According to Everhart, this should not exceed 0.25 per cent if " . . . fluid fertilizers produced from superphosphoric acid are the principal end products." (8) Lehr and McClellan add that "In Wet Process Acid, magnesium precipitates F in the reactor stage as colloidal phases that blind the gypsum filters. It raises the viscosity of Superphosphoric Acid, and is the primary cause of insoluble phosphate precipitates in ammonium phosphates liquid fertilizers." (9) Again, the Coronado Bank samples are in the problem range. Only four samples have undergone chemical analyses for magnesium oxide, but they show 1.0, 1.2, 1.2, and 1.13 per cent, respectively--considerably higher than the prescribed limits. Apparently the Coronado Bank does not have nodules with the desired chemical quality and the warning about inferring anything on the basis of data from Coronado Bank appears quite relevant. Unfortunately, no analysis is available for the other deposits with respect to magnesium oxide content, and future sampling and chemical analyses are needed to determine if they differ from those of Coronado Bank.

A fifth potential problem factor is that of the P_2O_5 to F ratio, which should be less than 8:1. The available data do not reveal any problem regarding this ratio for any of the deposits. This is not so for the content of organic matter in the available samples. For use as chemical raw material, the rock should not contain more than 0.5 per cent organic matter. "With increasing amounts of organic matter in sedimentary ore concentrates, the foaming problem in Wet Process Acid processes adds to reactor equipment costs, and discoloration of products reduces their market value and sales appeal." (10) It is evident from the LOI (loss on ignition) figures in the tables of chemical analysis that there is indeed a problem. Coronado Bank leads the deposits in unfavorable attributes with LOI figures ranging from 8.8 to 11.61 per cent. Santa Monica Bay deposits and Forty Mile Bank deposits show similar problems with samples reaching 10.37 per cent and 11.4 per cent, respectively. This does not imply that these deposits are not commercially exploitable, however.

It must be emphasized that the profitability of dredging phosphorites cannot be determined by evaluating a few selected aspects of the total operation. Rather, these many considerations must be integrated into the final derivation and consideration of the internal rate of return of the investment project. This technique of financial analysis basically obtains the rate of discount which equates the stream of expected returns from the investment with the stream of outlays for the investment. It is similar to the method of present value calculation, but in contrast to this the internal rate of return does not require prior determination of the discount rate. Rather, it solves for this rate. (11) Some of these chemical and mineralogical considerations cannot be easily integrated into the revenue or cost calculations; nevertheless, they can still be accounted for. In Chapter 8, after the estimated internal rate of returns have been calculated, a methodology for such analysis is presented.

References and Footnotes to Chapter 5

(1) Personal communication from William Richmond, May, 1976.

(2) Ibid.

(3) Everhart, Donald, "Evaluation of Phosphate Rock Deposits," International Minerals and Chemicals Corporation, February, 1971.

(4) Lehr, James R., and Guerry McClellan, "Phosphate Rocks: Important Factors in Their Economic and Technical Evaluation," TVA, 1974.

(5) Idem, ibid., p. 210.

(6) Personal communication from B. L. Murowchick, Chief Mineralogist, IMC.

(7) Blue, Thomas, and Thomas Torries, Phosphate Rock, Stanford Research Institute, Menlo Park, California, December, 1975, p. 760.0008J.

(8) Everhart, op. cit., pp. 3-4.

(9) Lehr and McClellan, op. cit., p. 211.

(10) Idem, loc. cit.

(11) For a further discussion of the internal rate of return technique, please consult the companion report on "An Economic Analysis of a Commercial Marine Sand and Gravel Mining Venture Offshore from southern California," by Paul A. Spindt and Walter J. Mead, NOAA, Office of Sea Grant, Department of Commerce.

6. OFFSHORE PHOSPHORITE MINING MODEL

6.1 Introduction

This chapter explores costs of two alternative technologies for dredging offshore phosphorites and their transportation onshore. The discussion is based primarily on information obtained from industry sources. Initial questionnaires sent to dredging companies produced valuable information and led to the establishment of contact with several companies which have provided generous assistance. Two different hypothetical dredging technologies are outlined. The first appears to be a generally accepted hydraulic suction dredging system, whereas the second is an innovative application of a jet lift mechanism to deep-sea dredging. Each system will be described without going into detail, since many particulars remain to be worked out. The purpose of this study is to make an initial attempt to describe technologies that appear viable for mining offshore phosphorites and to evaluate their production costs. Only future technological developments, pilot operations and actual full-scale dredging operations will determine whether either of the dredging systems presented can be profitably utilized in a commercial exploitation of phosphorites.

6.2 Technology I - Hydraulic Suction Dredge

The most distinctive feature of this dredging system is the utilization of submersible dredge pumps. Due to the barometric limitations inherent in centrifugal pumps, these cannot be utilized for dredging at great depths if the pumps are located in the hull or on the deck of a dredge. As some of the phosphorite deposits considered in this study are located under more than 1000 feet of water, this effectively prevents the use of centrifugal pumps mounted in the conventional way. However, a submersible dredge pump designed so that it could be installed on a dredge ladder and operate under water can be made to dredge efficiently at great depths. According to Sheehy, "By installing a dredge pump in a ladder, advantage is taken of a positive head on the dredge pump inlet and reduced suction losses. This results in an increase in the effective vacuum and a higher percentage of solids can be pumped. <u>The digging depth is no longer a major factor in production</u>." [our emphasis] (1) According to another industry source, the submerged dredge pump "...offers the advantage of continuous flow, good control of digging location and depth, and less abusive duty, generally, when compared to the dropping and digging of buckets." (2) Technologies like air lift and jet lift systems have received much attention in connection with manganese nodule mining. But these "... would require three to five times as much power plant as a dredge pump installation due to their inherent low efficiencies. This would increase total capital costs as much as 20%, depending on a number of other factors involving the whole system." (3) Dredging industry sources indicate, therefore, that a submerged pump dredging technology is a viable technological alternative.

A major part of this production system consists of dredge pumps and power plants installed in a pressure capsule located under the dredging vessel or platform. Both a barge type work platform and a seagoing vessel have been considered. Industry sources have recommended that a seagoing vessel be used. The capital and operating costs referred to later for this technology are derived on the basis of a seagoing vessel. These costs must necessarily be adjusted if a less expensive barge type of work platform is utilized. Because the vessels have a long life expectancy and a high production rate is assumed, these adjustments are not expected to affect greatly the final operating costs per ton of phosphorite. The effect on the internal rate of return for the project could, however, be substantial.

Electric motors with speed control would be required. It is assumed that diesel-driven generators would be utilized, though gas turbine generators could be used instead. Control of the suction line is achieved through the use of a hoist or a series of hoists. The suction pipe used could be either steel or high-pressure rubber hose. Apparently the latter would be preferable due to its flexibility. The dredge head would be located at the lower end of the high-pressure rubber hose. This could be of a similar type to that used on seagoing hopper dredges operated by the U.S. Corps of Engineers. The controls required would include a T.V. camera with a surface monitor, so that the dredging operation could be monitored. Gauges for recording dredge pump pressures, motor amps and vibration would also be required. The vibration gauge would indicate any plugging of the dredge pump and also when replacement of the impeller in the dredge pump is required.

Invariably, industry sources have expressed the opinion that only very high rates of production would be profitable for this type of operation. The calculation of the internal rate of return for both 1500 TPH (tons per hour) and a 350-400 TPH rate of production will determine whether a very high rate of dredging will in fact be required for a satisfactory return on investment. On the assumptions of a dredging rate of 350-400 TPH, 750 feet of water, 35-40 per cent solids dredged, about 14 feet/second minimum velocity in pipes as derived by postulating nodules of less than 8 inches in diameter, a slurry flow of 3450 gallons per minute was obtained and a minimum pipe size of 10 inches would be required. The calculations also postulated a total dynamic head of 288 feet. These are approximate conditions which will be encountered. The actual technical requirements and rate of production depend on graduation of particle sizes in the slurry, distribution of nodules and sand in the deposit, as well as numerous other factors. The considerations below, however, are seen as reasonable in the context of information presently available on deposit characteristics and dredging technology. The smaller rate of production and the associated pipe size are close to the assumptions of Mero and others. The larger rate of production, as indicated above, was recommended by industry sources. Based on an 18 inch production system (i.e., 18 inch suction and 16 inch discharge pipes), this yields a slurry flow of about 11,300 gallons per minute and requires horsepower of about 2200. Again, it must be stressed that these are approximations for the purpose of analysis. The system described would utilize two dredge pumps working in a series with each unit, developing a total dynamic head of around 140-150 feet. Two electric motors of about 1100 HP could be used, but we might also consider one 2200 HP electric motor with drive shafts extending from each side of the motor and thus driving two pumps. This type of arrangement is in operation in a quarry in Florida where a 1000 HP electric motor drives two 12 inch Thomas dredge pumps.

The possibility of washing, crushing and screening the phosphorites on board the ship has been considered, but the capital and operating costs of such an operation are not included in the cost calculations presented below. As stated above, the analysis assumes that a thorough exploration program precedes commercial exploitation. Therefore, only high-quality nodules are dredged with the exception of variable quantities of sand and silt. Given that upwellings of water are conducive to high precipitation of phosphate, according to geological theory, and that rich deposits are located on banks and similar elevations, it may not be unreasonable to assume that the amounts of sand and silt dredged with the nodules would not exceed one-third of the solid material. Only extensive exploration and sampling will determine whether this is in fact so.

It is likely that the higher rate of production assumed in this study, 1500 TPH, might be less compatible with a very small dilution ratio than the smaller production rate. If, for instance, the Quaternary Fill at any deposit is dredged, then the dilution ratio will be higher, resulting in higher dredging cost per ton of phosphate material. The general nature of this study and the lack of sufficiently detailed geological data on the deposits make it quite difficult, and arbitrary, to assume any particular dilution ratio. The procedure followed here is to assume the amount of debris dredged to be about one third of total solids, but then evaluate the sensitivity of the internal rate of return as this important assumption is varied.*(4) In these evaluations it must be acknowledged that the characteristics of the debris or foreign material will also be an important factor. If the operator is dredging exclusively for

*A change in the dilution ratio can be translated into either a corresponding change in dredging cost or a change in price obtained per ton. In 8.4 the latter approach is taken.

nodules and increasing amounts of sand and silt are dredged, the latter can be screened out without much difficulty. Given the required permission from federal authorities to dump the debris overboard, the costs of transportation and beneficiation might not be significantly affected. If, on the other hand, the debris comes in the form of rocks similar in size to the nodules, the situation would change considerably. At a production rate of 1500 TPH,it would be much more difficult to separate debris from nodules. Hand separation would be inefficient and very costly, and indications are that nodules and debris must be transported onshore where the beneficiation process would finally eliminate the debris. If, however, crushing to the point of liberation is required for this separation, then a problem arises in disposing of large quantities of finely crushed rock. An attempt will be made to indicate the effect on the internal rate of return of alternative assumptions about the quantities and nature of debris dredged.

Another possibility investigated was loading, at the dredge site, either all the material dredged or the separated high-phosphate material directly into bulk carriers. These would transport the material to overseas markets, especially Japan. Discussions with shipping experts, however, indicated that this would be a difficult, hazardous, and probably unprofitable undertaking; so it was decided not to pursue this any further. (5) Instead, this report assumes transportation of the dredged material to shore via barges for domestic processing. Further analysis will be developed in Section 6.6.

6.3 Costs of Technology I

The estimated capital cost for the dredging system described above is $9.0 million. This is predicated upon operation in 750 feet of water and on the other assumptions outlined for the production of 1500 TPH (or 1000 TPH of phosphorites). It also postulates a 15-year life of the main dredging system. The operating cost, inclusive of depreciation on a straight-line basis, is estimated at $4.50 per ton of material dredged. It is believed that lower rates of production will not cause substantial changes in capital costs, since most components of a 350-400 TPH (250 TPH of phosphorites) system will not vary greatly from those of a 1500 TPH dredging system. For the smaller rate of production, however, the estimated capital cost is around $7.5 million and operating cost is around $5.50 - 5.70 per ton of material dredged. Given the assumption of one third silt and sand dredged, this results in dredging costs of $7.50 and $6.00 for the 250 TPH and 1000 TPH rates of phosphorite production, respectively.

6.4 Technology II - Jet Lift Dredge

This type of dredging system has been suggested to us by Kiss and, apparently, represents a somewhat more radical approach to design than that of technology I. (6) Briefly, a new kind of hydraulic dredge is suggested where water under pressure is utilized to generate a jet-propelled stream of water. This can then be directed so as to force material up a dredge pipe. According to Kiss ". . .the invention relates to improvements in jet flow alternators and is more particularly concerned with a novel assembly comprised essentially of a multitude of telescoped tubes each bearing circumferentially spaced rows of perforations with a multitude of the perforations in each tube." These perforations are "disposed in radial alignment or for angular alignments one with the other in either direction along their length so as to direct flows of pressurized fluid toward either end of the assembly for propelling sludge or a liquid through the innermost tube." (7)

This study cannot evaluate either the novelty or viability of the engineering concepts embodied in this new dredging system. Only an outline of its main components is presented in addition to estimated capital and operating costs. For further details the reader is asked to consult the report by Kiss. (6)

One might question the superiority of this dredging system on the basis of the comment referred to above by another dredging expert. He stated that ". . .an air lift or jet lift system would require three to five times as much power plant as a dredge pump installation due to its low efficiency." (See Footnote 2.) The new design of the jet lift of technology II apparently makes this more efficient, and an energy savings of 43 per cent is claimed for the jet flow alternator over a "conventional method." ("Conventional" here refers to an identical technology without the innovations described briefly here.) Still, the dredging system will require a 2310 HP for a rate of production of 360 TPH. The capital and operating costs of this technology, however, are substantially lower than those reported above for technology I. These will be presented in the next subsection.

The novelties of this particular technology pertain to alternative flow suction dredges, being more particularly concerned with the construction and function of a novel suction head. This has two mouths disposed in opposite directions, one of which may be closed, so as to permit entry of slurry into the tube type ladder from one side or the other.

Such entry control also assists in movement of the ladder and its suction head in the direction of the work area. (8) The suction head utilizes vibration as well as the cutter to move into the working area. The jet flow alternator which is the other main novelty has already been described briefly. Basically, it is comprised of an outer shell and an inner pipe defining a tubular chamber between them. This chamber houses a number of axially shiftable tubes, telescoped tightly one over the other and over the inner pipe. The fluid pressure line opens into the chamber surrounding the tubes. When these tubes are in position to cause radial alignment of the series of circumferentially arranged parts in each tube and the pipe, the pressure entering through the aligned parts into the interior of the pipe is neutral. The tubes can be shifted to either side to offset the parts angularly. They can cause the water under pressure to exert a force in either direction depending on the angular offset of the parts. See footnote 7 for diagram. A more detailed analysis and graphical displays of this technology are presented in the report by Kiss.

6.5 Costs of Technology II

If this technology is indeed viable for this type of phosphorite dredging project, the crucial decision variable becomes the costs associated with this production system. The estimated capital and operating costs for a 250 TPH production system are presented in subsequent tables. These tables will also indicate the required equipment for each of the three main components of this dredging system, 1) pumps and power barge, 2) suction head and cutter head, and 3) surveying and operation control barge.

For this second technology, the estimated capital cost is approximately \$1.73 million for a 250 TPH system and \$3.64 million for a 1000 TPH system. The operating cost (including depreciation) is calculated to be about \$1 per ton of material dredged for a 250 TPH rate of production and about \$0.50 for a 1000 TPH operation, or about \$1.33 and \$0.67 per ton of nodules, respectively. (9) For comparison, the operating cost for technology I was estimated at \$7.50 and \$6.00 per ton of nodules for 250 TPH and 1000 TPH, respectively. Again, it must be pointed out that these costs would be higher per ton of phosphorites if a larger amount of debris is dredged. (For the remainder of this report the two production levels dealt with are 250 TPH and 1000 TPH, assuming a 1:3 dilution ratio when 375 TPH or 1500 TPH of material is actually dredged.)

TABLE 33. CAPITAL COST OF PUMP AND POWER BARGE COMPONENTS, 1976 DOLLARS

Hull, new	\$220,000
Superstructure	110,000
Diesel engines	120,000
Air compressor	40,000
Main pump	60,000
Electric power generator	30,000
Telescopic tie-tuber, by hydraulic movements	20,000
Boostermatic discharge pipe, say 215 ft @ \$50,000/ft	10,750
Operator console, hydraulic and/or air control	15,000
Radar, sonar ship to shore radio	45,000
Gantry crane, plus other (heating, cooling)	35,000

Table 33 (continued)

Service pump	$ 10,000
Fuel tanks	10,000
Facilities for five men (kitchen, sleeping, restroom)	10,000
Hydraulic grids and engines, "Christmas tree"	12,000
Winch and winch engines	16,000
Cables and anchors	25,000
Life boats	10,000
Total pump and power barge	$798,750
Unforeseen expenses	79,875
TOTAL	$878,625

Source: Kiss, Sandor G., An Analysis of Design and Performance of a Sub-sea Dredge (SSD), for the Mining of Deep Sea Minerals, Phosphorites, June, 1976.

TABLE 34. CAPITAL COST OF SUCTION AND CUTTERHEAD ASSEMBLY, 1976 DOLLARS

Cutterhead - custom made	$ 12,000
Vibrator mechanism	15,000
Self-propelling drills	15,000
Jet flow alternator	15,000
Boostermatic suction pipe, 1000 ft @ $50.00/ft	50,000
Subsea lighting system	5,000
Television focusing camera	20,000
Total suction and cutterhead	$132,000
Unforeseen expenses, 10%	13,200
TOTAL	$145,200

Source: Refer to Table 33

TABLE 35. SURVEYING AND OPERATING CONTROL BARGE, 1976 DOLLARS

Hull, new	$110,000
Superstructure	55,000
Operator's board, electric control panel, etc.	25,000
Diesel generator	40,000
Inboard motors	15,000
Tandem control of propellers, shafts, etc.	10,000
Service pump	5,000
Winch and engine with cables (for the cutterhead)	12,000
Open bottom housing for cutterhead (close-open)	10,000
Television set on bottom	5,000
Echo sounding system	10,000
Raydist shore locations	10,000
Radar, sonar, ship-to-shore radio	45,000
Fuel tanks	5,000
Facilities for three men	10,000
Life boats	10,000
Total surveying and operating control	$377,000
Unforeseen expenses, 10%	37,700
TOTAL	$414,700

Source: Refer to Table 33

6.6 Barge Transportation

This type of delivery system has usually been assumed in previous studies of offshore phosphorite mining. No technical or economic analyses of viable alternatives have been found. Therefore, this study will also assume a barge transportation system. Concern has been expressed, however, regarding the dangers and hazards involved in this type of ocean transportation. One industry source writes ". . .it is appalling to consider the hazards of barge loading in Pacific ocean swells, or the scheduling of delivery in the face of rapidly changing weather conditions." (10) An alternative system is suggested by taking advantage of the fact that the dredged material is already in the delivery system when hydraulic dredging is used. "Simply by extending the material handling pipe and adding submerged booster pumps as may be required, a virtually weather-proof delivery system is provided." (11) This type of hydraulic delivery system, pumping the phosphorites to shore via pipes, would seem to offer several advantages over a barge transportation system. But it appears that this type of hydraulic delivery system would be more appropriate for mining operations close to shore. For instance, mining in the Santa Monica Bay could possibly utilize this type of transportation system. Here parts of the deposit are located as close as about 3 miles from shore and extending out to about 15 miles. From the available information about this type of system it appears that it would have the advantage of being less visible, would avoid sea traffic hazards associated with barge transportation, and might well involve less pollution of the sea envirnment. No information has been obtained, however, on how the delivery pipes would be located so as not to obstruct sea traffic and, most important, no cost estimates for constructing and operating such a system have been made available.

In addition to the lack of available information to evaluate an hydraulic delivery system for both short and long distance transportation, data on weather conditions also seem to indicate a less problematical situation than some people fear. It is learned that ". . .restricted fetches allow only the development of low waves with short lengths and periods. Larger waves (to 8 feet) are formed during frontal crossing, but again with short lengths and periods due to limited fetches. It is only when gale winds blow from the west at 35 knots or more that high waves are formed in the local region and travel over the shelf." (12) Also, sampling undertaken by the Naval Weather Service Command has found waves of 8 feet or more in only 3 per cent of the observations. Discontinuing dredging operations in problematical weather conditions would be one way to handle difficult situations. Since this analysis assumes 200 days of operation per year, it leaves considerable room for dredging stoppages due to various unforeseen situations including bad weather.

Some previous studies have assumed purchasing used barges for transportation of the phosphate rock. In this case, however, it is much more difficult to assume the existence of a used market for barges and, even more difficult to determine a purchase price for them. Presently available information indicates that no large, used barges are available. Some government surplus barges of about 1000 tons are reported available, but these would be too small for this operation, even for the 250 TPH rate of dredging if the assumptions above are not changed. The demand for barges in the North Slope oil exploration and development partly explains why large used barges are not available. (13) Also, there has apparently been no great demand for them until developments started in Alaska. New 12,000 ton barges of the type considered above for long-term chartering would cost between $3.0 and 3.5 million each (14), but this analysis assumes that they would be bought if chartering were not undertaken. A supply of used barges can possibly be seen forthcoming as resulting from the lesser need for large barges in Alaska. The purchase price chosen would necessarily be extremely arbitrary. It is preferable, therefore, to base the analysis on long-term chartering for which cost information is more accessible. Furthermore, economic theory would predict equal cost for purchasing and chartering given identical technologies. This does not have to hold exactly in a real world situation, where lack of competition, the existence of transaction costs and institutional peculiarities often prevail, but it is reasonable to expect this to be the case generally. For these reasons, therefore, the analysis deals exclusively with chartering of barges for transporting the marine phosphorites.

Under long-term contract with a local barge and tug operator, the estimated cost for this type of operation would be $4000 per day for each 12,000-ton barge and $3500 for each tug chartered. (15) It is also estimated that about $1200 in fuel per tug will be required. A 1500 TPH rate of production, or 1000 TPH of phosphorites under the above assumption, would require three barges and one tug. Assuming 80 nautical miles towing distance from the deposit to the Long Beach Harbor, a towing speed of 10 knots and equal rates of loading and unloading, at 1000 TPH, a cycle time of 40 hours is derived. It must be remembered that actual dredging, loading, and unloading require four hours down-time. Under those requirements, a continuous use of the tug is achieved while the barges must necessarily be affected by the down-time.

Only 200 days operation per year is postulated to allow for 1) unforeseen difficulties, 2) repairs and upkeep, and 3) bad weather conditions. For a smaller 250 TPH operation, a cycle similar to that of 1000 TPH is assumed for high-capacity utilization. Now, however, barges of 3000-4000 tons will be required. Under these assumptions the result is a total operating cost per day for barges and tugs of $16,700 or $0.84 per ton of nodules when 1000 TPH are dredged. For the smaller 250 TPH operation, the estimated operating cost is $1.00 per ton of nodules.

6.7 Unloading

Two types of technologies for unloading are considered below. One of these assumes the use of dredge pumps. This method has been used in previous studies and has been suggested by industry sources. The second unloading technology is being utilized in the sand and gravel dredging industry in the United States, Great Britain, and elsewhere and is thus a technologically proven system. It uses large buckets to move the ore into hoppers from which conveyors take it to the onshore destination. The required capital equipment and manpower for this part of the operation depend on the type of docking facilities used as well as how far away from the docks the processing plant is located.

6.7.1 Land

This analysis takes Long Beach as the unloading port and while most of the costs below will not be specific to this port, this will be the case for estimating land acquisition costs. Unused land is currently not available in Long Beach harbor; therefore, land must be bid away from present uses. Based on available information, the resulting purchase price is estimated to be $3.00 per square foot. The space required for unloading, storage, and beneficiation may be divided into an oceanfront site for unloading and an inland site for processing. This analysis, however, does not attempt to determine the nature or extent of such a division. Rather, a uniform price for an assumed total land requirement of 20 acres for the 250 TPH operation and 30 acres for the 1000 TPH operation is utilized. If the operator decides to locate the plant farther inland, it is possible that the postulated price of land is too high. Such a decision will, on the other hand, increase the handling and transportation cost of the ore. The above assumption on land and its price, therefore, might serve as a sufficiently good approximation for this study. For other ports, on the other hand, conditions might vary considerably. State and local regulations for land use are most likely to require a thorough evaluation of any proposed industrial project that will affect the waterfront. This aspect of a potential phosphorite dredging project will be given further attention in the concluding sections of this report. Finally, it should be pointed out that land is treated as nondepreciable capital. It is further assumed that the land appreciates at a rate equal to the internal rate of return. (16) This yields a total land acquisition cost of $2.61 million for the 250 TPH rate of production and $3.92 million for the 1000 TPH production system.

6.7.2 Conveyor Unloading

This system consists of large buckets which move along cables suspended between the bow and stern. These move the ore into hoppers located at either end of the barge from where conveyors transport the material onshore. With 3-cubic-yard buckets this system is reported to unload about 500 tons per hour. Doubling the capacity of the components would make this suitable for the 1000 TPH rate of dredging. It is estimated that this discharge system would require about $450,000 in capital equipment for each barge used, when 500 TPH are unloaded. The estimated cost for 1000 TPH is $600,000. In addition, two operators would be needed to work the equipment. For a 1000 TPH rate of dredging, this yields capital costs of $1.8 million and operating costs of $0.14 per ton of nodules. For the 250 TPH rate of dredging, capital costs are $1.35 million and operating costs become $0.22 per ton of nodules.

6.7.3 Hydraulic Suction Unloading

This system is considered particularly appropriate for high rates of unloading. Some of the main capital components are given and costed in the following table.

TABLE 36. CAPITAL COST COMPONENTS OF HYDRAULIC SUCTION UNLOADING, 1000 TPH OPERATION, 1976 DOLLARS

Two dredge pumps	$136,000
Two 700 hp motors	140,000
Prime motor and water pump	20,000
Piping, 1000 feet	31,000

TABLE 36 (continued)

Barge modifications for hydraulic suction unloading, three barges	$225,000
Miscellaneous	100,000
	$652,000

Although little information is available on the life of these components for this type of operation, it is probable that the dredge pumps will not survive for 15 years without major replacements and repairs. Maintenance will take place throughout the assumed 15 year life of the project; but to simplify calculations, these additional capital costs will be integrated into the initial lump sum capital investment. It is assumed, therefore, that total capital investment for the unloading system is $1 million for the 1000 TPH operation and $0.75 million for the 250 TPH operation. With these assumptions, operating costs will be $0.21 and $0.23 per ton of phosphorites for the 1000 TPH and 250 TPH operations, respectively. These calculations ignore various potential difficulties that a project of this type is likely to encounter. The issue of water disposal arising from the use of hydraulic discharge must be considered. Unless a closed system is developed, the water must be disposed of and whichever solution is found, it is certain to add to operating and capital costs. Additional pumps, motors, and pipes can be used to pump the water to a suitable discharge point. If only nodules are unloaded, the water used is unlikely to require more purification before disposal. This might not be the case during the beneficiation stage, however, and this is dealt with in Chapter 7. Before proceeding, the estimated capital and operating costs for dredging, barge transportation, and unloading are summarized in the following table.

TABLE 37. ESTIMATED CAPITAL AND OPERATING COSTS FOR OFFSHORE PHOSPHORITE DREDGING, BARGE TRANSPORTATION, AND UNLOADING, 1976 DOLLARS

	DREDGING TECHNOLOGY I				DREDGING TECHNOLOGY II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
UNLOADING ARRANGEMENT:	SUCTION	CONVEYOR	SUCTION	CONVEYOR	SUCTION	CONVEYOR	SUCTION	CONVEYOR
A. Dredging								
1. Capital Costs $ million	7.50	7.50	9.00	9.00	1.73	1.73	3.64	3.64
2. Operating Costs dollar/ton	7.50	7.50	6.00	6.00	1.33	1.33	0.67	0.67
B. Barge Transport								
1. Capital Costs $ million	-	-	-	-	-	-	-	-
2. Operating Costs dollar/ton	1.00	1.00	0.84	0.84	1.00	1.00	0.84	0.84
C. Unloading								
1. Capital Costs $ million land	0.75 2.61	1.35 2.61	1.00 3.92	1.80 3.92	0.75 2.61	1.35 2.61	1.00 3.92	1.80 3.92
2. Operating Costs dollar/ton	0.23	0.22	0.21	0.14	0.23	0.22	0.21	0.14
TOTAL CAPITAL COSTS	10.86	11.46	13.92	14.72	5.09	5.69	8.56	9.36
TOTAL OPERATING COSTS	8.73	8.72	7.05	6.98	2.56	2.55	1.72	1.65

References and Footnotes to Chapter 6

(1) Sheehy, G.D., "Submersible Dredge Pump - An Answer for Deep Dredging," World Dredging, March, 1975, p. 25.

(2) Personal communication from Charles E. Woodbury, P.E., Tampa, Florida, November, 1975.

(3) Ibid.

(4) In defense of this dilution ratio it can be pointed out that Mero (1959), in his fairly brief analysis of suction dredging assumed "40% proportion of debris in pipeline." See John Mero, An Economic Analysis of Mining Deep Sea Phosphorite, Ph.D. dissertation in Mining Engineering, University of California, Berkeley, July,1959.

(5) Personal communication from San Francisco shipping company, June, 1976.

(6) Kiss, Sandor G., An Analysis of Design and Performance of a Sub-sea Dredge (SDS), for the Mining of Deep Sea Minerals, Phosphorites, Continental Dredge and Marine Corporation, June 15, 1976.

(7) Idem, ibid., p. 61. See figure below (next page)

(8) Idem, ibid.

(9) Personal communication from Sandor Kiss, Continental Dredge and Marine Corp., June, 1976.

(10) Personal communication from Charles E. Woodbury, P.E., Tampa, Florida, November, 1975.

(11) Ibid.

(12) Bureau of Land Management, 1975, Final Environmental Impact Statement, Proposed 1975 OCS Oil and Gas General Lease Sale Offshore Southern California, printed by Department of the Interior, Vol. IV.

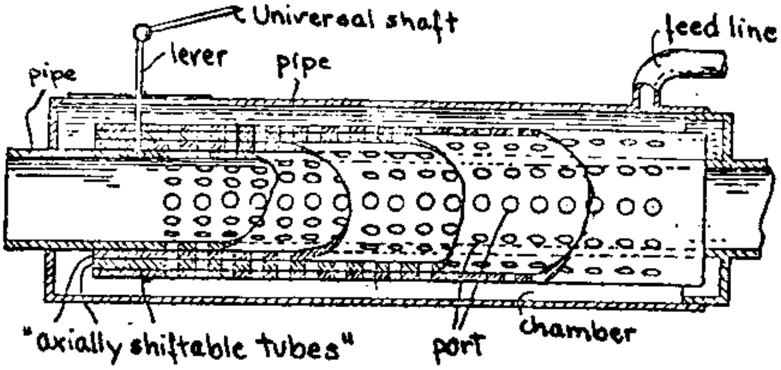
(13) Personal communication from barge and tug leasing company, July, 1976.

(14) Personal communication from a representative of Bethlehem Steel, San Francisco.

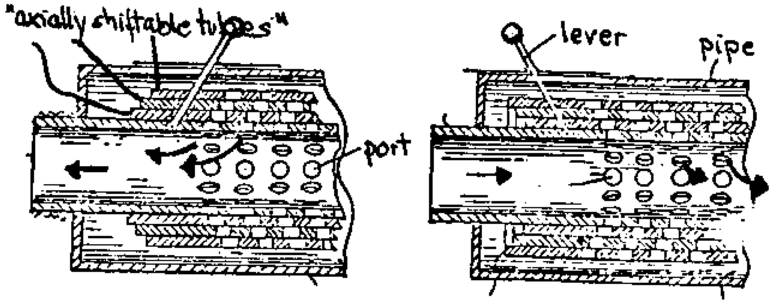
(15) Personal communication from barge and tug leasing company, July, 1976.

JET FLOW ALTERNATOR - Footnote (7) p. 125

A. Tubes in neutral position



B. Tubes in position to discharge in direction of arrows.



Source: Kiss, Sandor; Op. Cit., p. 61.

References and Footnotes to Chapter 6 (continued)

(16) This greatly simplifies calculation of the internal rate of return in the following way by reducing the present value of investment:

$$E_o - \frac{2,613,600\ (1+i)^{15}}{(1+i)^{15}} \text{ to}$$

$[E_o - 2,613,600]$. It also prevents capital gain from land appreciation from distracting the financial evaluation of the phosphorite mining and processing activity per se.

7. BENEFICIATION

7.1 Introduction

Marine phosphorites have not been exploited commercially and the literature on phosphorites contains little on beneficiation. It is difficult, therefore, to prescribe beneficiation methods and determine the costs involved. Some researchers have discounted problems in this production stage and assumed simple beneficiation methods with low capital and operating costs. An example of this view can be seen in a statement by a representative of Collier Carbon and Chemical that ". . .processing of the nodules will be no problem; they will be fed through the same processing plants that now handle phosphate rock that Collier has to buy." (1) Others have been less optimistic about beneficiation methods and associated costs. For example, Sorensen and Mead in their study (2) assumed a beneficiation and processing cost of from \$2 to \$5 per ton of material, for a process that would include acid leaching. The discussion below, based on presently available information and prices, estimates the costs for the assumed beneficiation steps.

7.2 Beneficiation Tests on Phosphorites

For a specification of beneficiation processes one should know, besides the chemical data, the mineralogical composition and the textural relationships existing in the ore sample. In the report by Fisher and Richmond one can find tables with collected chemical analyses of southern California borderland phosphorite deposits. These provided the basis for the considerations in Chapter 5 of potential problems which might be encountered when utilizing the phosphate rock produced from these phosphorites as feed in the production of various fertilizer end products. As was discussed in more detail in Chapter 5, concern was expressed relative to high 1) iron and aluminum content, 2) weight ratio of CaO to P_2O_5, 3) magnesium oxide, and 4) organic material. Again, it must be repeated that the nature of the sampling process makes it quite dangerous to infer that the same problems exist in all deposits. Even if these should be similar to the samples that are available and have been analyzed, it is still not certain how the beneficiation process and its costs would be affected. The evidence presented does suggest, however, that the sludges and precipitation as well as the excessively high consumption of sulphuric acid are likely to lower the selling price of the resultant phosphate rock if this is to be used in phosphoric acid production. Also, lower prices will result from a high organic content of the rock produced from marine phosphorites. This is partly because of discoloration of phosphoric acid produced from such rock. It should be mentioned that these problem areas will be less significant if other end products are produced from the phosphate rock. (3)

The considerations with respect to the chemical analyses, therefore, are closely tied to the end uses of the phosphate rock. Our next, and final, chapter will evaluate likely maximum prices for the phosphate rock produced from southern California phosphorites.

Most analyses available on beneficiation deal with Florida and Western phosphate ores which are commercially exploited. Few deal with beneficiation of marine phosphorites. The marine phosphorites would apparently require quite different beneficiation processes. But no industry source has been able to specify an appropriate process owing to lack of available information on chemical and mineralogical composition and textural relationship in the phosphorites. A few reports, however, have been obtained that present results of spectrographic analysis of phosphorite samples, calcination, slaking and acid treatment. (4) An IMC report made available for this study states that ". . .examination of sized fractions indicates that liberation of glauconite and quartz is about 80% mesh. The iron oxide is very finely disseminated throughout the phosphorite and cannot be liberated at a practical size." (5) With respect to the possibility of upgrading by magnetic separation, it is found that only a slight increase in grade and slight decrease in insol and Fe_2O_3 result. Flotation, a major step in current beneficiation methods of onshore phosphate ores, was not attempted in the IMC tests. It was felt that it would not be economically feasible to remove a ". . .relatively low silicate gangue content" (6) in this way. The market situation for phosphate rock and technological developments have changed sufficiently from 1964, making it unclear what would currently be economically feasible in terms of beneficiation methods. Indications are, on the other hand, that flotation will still not be employed in efforts to raise the grade of the phosphate rock produced from phosphorites. (7) This conclusion is supported by the results of extensive flotation tests reported by Buckenham, Rogers, and Rouse. Four different tests were performed on a sample assaying 19.3 percent P_2O_5, 32.3 percent $CaCO_3$ and 0.6 per cent K after washing and screening. "Flotation investigations covered anionic flotation of apatite and/or calcite and cationic flotation for the removal of quartz and feldspar from the finely ground nodule sample before and after calcination." (8) Seven approaches were investigated:

1) Direct fatty acid flotation
2) Fatty acid flotation with apatite depression
3) Fatty acid flotation with calcite depression
4) Fatty acid/kerosene flotation with calcite depression and multistage cleaning
5) Direct sulphonate flotation
6) Direct amine flotation
7) Double flotation (fatty acid/kerosene followed by amine) with calcite depression and multistage cleaning

The conclusion reached from these tests states that "unsatisfactory results were obtained throughout the flotation study." (9)

Other tests performed on marine phosphorites have dealt with calcination, slaking, and acid treatment. "Calcination tests were done in a gas-fired furnace with free air flow across samples prepared to 100% finer than 10 mesh B.S.S. Following calcination for variable times (30-90 minutes) at different temperatures (850^{o}-$1,000^{o}C$), samples were slaked with water and deslimed at 10 microns by cycloning." (10) These tests appear to have been undertaken for the purpose of investigating the various properties of the phosphorites. The most economical processing methods for a specified, desired level of P_2O_5 for the final product have not been analyzed. Clearly, the costs associated with the various processes and the extent of the processing done must be analyzed before the operator can determine the nature and extent of desired beneficiation. At that point a complete flow sheet of the operation can be developed.

Some industry sources feel the extent of processing reported by Buckenham, Rogers, and Rouse would not be economical for commercial exploitation of marine phosphorites. The temperatures during calcination, especially, could lead to excessive fuel costs. Although the grade would be raised and a higher price could thus be obtained for the product, it appears that this would not sufficiently compensate for the much higher fuel costs. In one case, reported calcination at 900°C, or 1652°F, was carried out for one hour and the P_2O_5 level was raised from 19.3 to 25.2 per cent. A better result was reported when 90 per cent of the P_2O_5 in the nodules (17.6 per cent P_2O_5) was obtained in a 28.9 per cent P_2O_5 product. This followed calcination of ground nodules (94 per cent minus 10 mesh) at 875°C (1607°F) for 90 minutes and leaching three times with 1 M ammonium chloride. (11) If the phosphorites of interest contain a high percentage of organic material, however, as do most of those in the offshore southern California borderland, the fuel costs might not be significant at all. This results from the high BTU value of the organic material in the phosphorites. (12)

7.3 Postulated Beneficiation and Estimated Capital and Operating Costs

On the basis of such limited information, it is necessarily very difficult and arbitrary to specify definite beneficiation processes on which estimated costs can be calculated. Much testing and analysis of the phosphorites must be completed before one can combine these results with the prices of the various factors of production to obtain an optimum combination of beneficiation processes for maximum profit. Despite lack of available information required for such complete analysis, an attempt is made below to evaluate one possible beneficiation procedure and its associated costs. In this way the reader can get some idea of what a given set of explicit assumptions about beneficiation will yield in terms of capital and operating costs. If these assumptions are considered inappropriate, they can be replaced and new cost estimates can be obtained.

On the basis of discussions with industry sources it is assumed that crushing, screening, and calcination will be undertaken. Crushing would be stepwise, first to somewhere less than 48 mesh (the reported point of liberation of phosphate in phosphorites), say 35 mesh. Screening would then follow at 48 mesh and thus the high grade would be scalped out. The material not passing 48 mesh would require additional crushing until an appropriate cutoff point is reached for obtaining the desirable P_2O_5 content. If the phosphorites mined are very high in P_2O_5 content, not much non-phosphatic rock needs to be removed to obtain the specified grade of P_2O_5 in the rock. If the phosphorites happen to contain 32 per cent P_2O_5 when dredged, for example, nothing more than crushing would be required to obtain a rock of this specified grade. To remove any organic material, calcination would also be necessary. The average P_2O_5 content of phosphorite nodules recovered in the deposits under consideration (and on which information is available) is 25.47 per cent. If a phosphate rock of around 30 per cent P_2O_5 or above is desired, therefore, indications are that some degree of upgrading must be undertaken. One could assume, however, that sufficient quantities of high-grade phosphorites have been located prior to commercial exploitation so that only crushing and calcination would be required (i.e., no screening for upgrading would be necessary). Also, if a lower grade were found, this could still be the only processing done, but then a lower grade rock would be sold at correspondingly lower prices. In the latter case, the costs of further upgrading would need to be assessed against higher prices obtained for higner grade rock. (One is reminded that the prices of phosphate rock, evaluated in Chapter 2, increase more than proportionately with increases in grade of P_2O_5.)

A large number of different types of crushersare available for the kind of crushing and pulverizing required. The components specified in Table 38 below comprise only one alternative but will, hopefully, represent a useful approximation for our purpose. The crushers are connected with conveyors; sizing screens are located in such a way as to scalp out the high-grade material according to a predetermined flow-sheet specification. Dust collectors are also very important parts of the crushing and calcining processes as well as in storage areas and loading operations. Dust regulations vary according to location and identity of the government agency with jurisdiction. But these regulations are becoming increasingly restrictive. If the processing plant were to be located in Long Beach, for example, it is most probable that considerable costs would be incurred for compliance.

On the basis of available information, it seems likely that calcining will be required to remove very high organic matter contents of southern California marine phosphorites. It is clear from Tables 38 and 39 that this step in the processing comprises a very substantial part of total capital costs. Alternative technologies for calcining are available but are apparently of variable reliability. (13) Although this analysis assumes the usage of calciners that are very expensive (and reliable, according to our sources), a more detailed feasibility study would need to evaluate the trade off between higher costs and less risk of breakdown, etc. Detailed information on the probabilities of breakdowns during various situations must then be known for each technology. This, in addition to their costs, would provide sufficient data to calculate minimum expected costs for calcination equipment.

It is also extremely difficult to specify the nature and extent of required construction of buildings and sheds, storage (concrete or steel silos are commonly utilized) and shipment facilities. These are unique to each plant and its type of operation. Also, costs are likely to vary according to what proportion of the phosphate rock produced will be shipped to domestic markets as opposed to foreign markets. This would not be so if both markets require transportation by ship and, therefore, identical shipping facilities. This analysis cannot do more than give rough estimates for what the required capital costs will be for such facilities. In Tables 38 through 41, however, the estimated capital and operating costs for the beneficiation stage of production are presented for a 250 TPH and a 1000 TPH operation.

TABLE 38. ESTIMATED CAPITAL COSTS FOR BENEFICIATING EQUIPMENT, 250 TPH OPERATION, 1976 DOLLARS

1. Crushing		
Jawcrusher	$ 80,000	
Rollcrusher	40,000	
Fluff-mill	125,000	
	$245,000	
Screens, conveyors, dust collectors, etc.	155,000	
Crushing equipment		$400,000

Table 38 (continued)

2. Calcining		
Five units, each processing 50 tons/hr @ $2.8 million fully installed		$14,000,000
3. Storage facilities, shipment facilities, etc.		2,000,000
TOTAL		$16,400,000

TABLE 39. ESTIMATED CAPITAL COSTS FOR BENEFICIATION EQUIPMENT, 1000 TPH OPERATION, 1976 DOLLARS

1. Crushing		
Jawcrusher	$170,000	
Rollcrusher	85,000	
Fluff-mill	265,625	
	$520,625	
Screens, conveyors, dust collectors, etc.	229,375	
Crushing equipment		$ 750,000
2. Calcining		
20 units, each processing 50 tons/hr @ $2.8 million installed		$56,000,000
3. Storage, shipment facilities, etc.		4,000,000
TOTAL		$60,750,000

TABLE 40. OPERATING COSTS PER TON FOR CRUSHING AND CALCINING, 250 TPH OPERATION, 1976 DOLLARS

1. Labor and Power		
Labor		
Two men for crushing	$0.08	
Two men for calcining	$0.08	
Total labor costs		$0.16

Table 40 (continued)

Power			
Crushing, 2000 hp = 1756 kW*; 1756 · 3¢/250	$0.21		
Calcining, 6000 hp = 5268 kW; 5268 · 3¢/250	$0.63		
Total power cost		$0.84	
Total labor and power costs			$1.00
2. Depreciation of crushers and calciners and other facilities			
$16.4 million/[(250 tons/hr) · (20 hr/day)(200 days/yr)] · 15 yrs =			$1.09
3. Maintenance and repairs of crushers, calciners and other facilities; calculated at 5 per cent of capital costs**			
$16.4 million/20 · (250 tons/hr)(20 hrs/day) (200 days/yr) =			$0.82
Total operating cost for beneficiation			$2.91

*1 hp = 746 W

Assuming 85 per cent efficiency

0.85 hp = 746 W or 1 kilowatt = 0.85/0.746 = 1.14 hp

or, equivalently, 1 hp = 0.746/0.85 = 0.878 kW

**5 per cent might be considered somewhat high, but it is set at this level partly because of the rather long (15 years) life we have assumed for the equipment.

TABLE 41: OPERATING COSTS PER TON FOR CRUSHING AND CALCINING, 1000 TPH OPERATION, 1976 DOLLARS

1. Labor and Power			
Labor			
Five men for crushing	\$0.05		
Seven men for calcining	\$0.07		
Total labor cost		\$0.12	
Power			
Crushing, 4500 hp = 3951 kW			
3951 kW · 2.5¢ /1000 =	\$0.10		
Calcining, 25,000 hp = 21,950 kW			
21,950/kW · 2.5¢ /1000 =	\$0.55		
Total power costs		\$0.65	
Total labor and power costs			\$0.77
2. Depreciation of crushers, calciners and other equipment			
\$60.75 million / (1000 tons/hrs)(20 hrs/day) (200 days/yr)•15 yrs			\$1.01
3. Maintenance and repairs of crushers, calciners and other facilities, calculated at 5 per cent of capital costs			
\$60.75 million/20 · 4 million tons/yr.			\$0.76
Total operating cost for beneficiation			\$2.54

In the second section of the next and last chapter the various capital and operating costs will be combined for complete economic evaluation. Assumed exploration costs, phosphorite dredging costs (including transportation and unloading), beneficiation and overhead costs will be summarized. On the basis of the assumed maximum price (discussed in part 1 of that chapter) of the phosphate rock and the costs just described, internal rates of return will be calculated for the various technological combinations that have been evaluated.

References and Footnotes to Chapter 7

(1) Business Week, June 30, 1962, p. 146.

(2) Sorensen, Philip E., and Walter J. Mead, "A New Economic Appraisal of Marine Phosphorite Deposits Off the California Coast," Marine Technology Society, The Decade Ahead, 1970-1980.

(3) Personal communication from a representative of Fertilizers and Chemicals Ltd., Haifa, Israel.

(4) Mineralogical Examination of California Submarine Phosphorites, report No. 2520, IMC, January, 1964.

Buckenham, M. H., J. Rogers, and J. E. Rouse, "Assessment of Chatham Rise phosphate," Paper No. 8, presented at the Australasian Institute of Mining and Metallurgy, 1971 Annual Conference.

(5) IMC, op. cit., p. 19.

(6) Ibid., p. 20.

(7) Personal communication from anonymous California Research firm, June, 1976.

(8) Buckenham, Rogers, and Rouse, op. cit., p. 10.

(9) Idem. ibid., p.11

(10) Idem. ibid.

(11) Idem. ibid.

(12) Personal communication from anonymous California Research firm, 7/16/76.

(13) Ibid.

8. ECONOMIC EVALUATION

8.1 Revenue Considerations

Section 2.5 described and evaluated price developments of phosphate rock. Both the substantial price increases since early 1974 and the interesting relationship between phosphate rock prices and the grade of P_2O_5 were analyzed. Table 31 gives a good picture of this latter phenomenon. On the basis of previous discussions, this analysis will be mostly concerned with the first three grade classifications which range from 66 - 72 per cent BPL (or 30.22 - 32.98 per cent P_2O_5). In 1975, the prices for these classifications (66 - 68 per cent BPL, 68 - 70 per cent BPL and 70 - 72 per cent BPL) are listed as $31.00, $35.50, and $40 per ton of rock F.O.B. Florida. The price at which the phosphate rock produced from California marine phosphorites will be sold will be determined, of course, by supply and demand at the time.

This analysis makes the simplifying assumption that the entire investment required for this type of project is made in the first year. Thereafter, it is further assumed that production takes place at full capacity for each of the subsequent 15 years. (1) It is required, therefore, that the selling price of the phosphate rock be specified for each of these 15 years or that an average selling price be assumed on the basis of projected supply and demand developments. Implicit in these supply and demand considerations is the aspect of the chemical and mineral composition of this rock and to what extent any discount is required to make it competitive with rock from alternative sources. Also, the transportation advantages of phosphate rock produced from southern California phosphorites must be evaluated. This factor is particularly significant for the domestic market. The locational advantage with respect to supplying Valley Nitrogen, for instance, will likely play an important role in the overall profitability of the project. Any locational advantages relative to foreign markets are much more uncertain. Much attention has been paid to the market potential in Japan for California phosphate rock, and Sections 2.2.2.5 and 2.4.5 showed why this has been the case. The fact that Florida and African countries have supplied a large part of this market would seem to indicate a market potential for a California-based operation. This would, of course, require production of the kind of rock that the Japanese market demands. The fact that Japan imports high-quality rock could limit the extent of the Japanese market potential. This would depend on 1) the quality of phosphorites found and the costs of beneficiation required to make the rock produced comparable to that of competitive sources, 2) the quality and production costs of these competing rocks, and 3) their transportation costs. Regarding this last point, it is interesting to note the sizable transportation cost advantage which a California producer would have relative to a Gulf producer, <u>ceteris paribus</u> (i.e., everything else held constant or all other conditions being the same for the two producers). Based on a time charter, the transportation costs to Japan would be \$10.15 and \$18.50 for the California and the Gulf (Florida) producer, respectively. (2) Everything else is not the same for these two producers, however, and industry sources report that the California producer is currently at a disadvantage as to return cargo on this trade. Therefore, the transportation advantage at present is much smaller than specified. Indeed, current transportation costs to Japan for Gulf phosphate producers are reported to be about $10 with return cargo. A California producer would, therefore, also need backhaul in order to gain a transportation cost advantage to the Japanese market. It is extremely dangerous, however, to rely heavily on any specified rate quoted, since shipping rates fluctuate notoriously and the figures given above could change substantially as the market conditions change.

A California phosphate rock producer will concentrate on those markets where his locational advantage is greatest. For the smaller production level considered (1 million tons per year), it will be assumed that everything produced will be sold domestically. In this context one is reminded that Valley Nitrogen alone at this time of writing (i.e., end of 1976) consumes in excess of 500,000 tons of phosphate rock. In Section 2.4.1 a total "domestic" (including western Canada) western market was calculated to be around 2 million tons. Considering the locational advantage of Idaho, Wyoming, and Utah producers in some of these markets, it is unlikely that a California producer would be able to compete successfully in all of these western markets. Capturing 50 percent of this market does not seem unreasonable, however. A level of operation of 1000 TPH, or 4 millions tons annually, will most likely require penetration in foreign markets. High railroad transportation costs per ton of phosphate rock will make Pacific Basin markets most attractive, particularly if sufficient backhaul cargoes can be found.

Instead of attempting to project price movements of phosphate rock for each of 15 consecutive years, an average price for the entire 15-year period is assumed. This price reflects both the discount required due to chemical and mineral composition and price fluctuations due to supply and demand conditions. Industry sources report that substantial price decreases are expected in the near future. It is extremely hazardous to project an average price for 15 years into the future. This is even more so when discounts due to the lower quality rock must be accounted for. Here it is assumed that the average price is $25 before a 25 per cent discount. Thus, an average price of $18.75 is expected for a 250 TPH operation. For the larger 1000 TPH rate of production it is assumed that an average price of $23 results before, and $17.25 after, the discount. These assumptions yield a total gross revenue for the 15-year period of $281.25 million for the smaller, and $1035 million for the larger, rate of production.

8.2 Cost Considerations

The need for a substantial exploration program prior to commercial exploitation has been brought up repeatedly in this study. Given the large investment required in both dredging and beneficiation as well as the unique pricing structure for phosphate rock of different grades, it would be important to complete a comprehensive exploration program before initiation of commercial dredging. Kaufman and Siapno divide a commercial exploration program into four principal efforts: (i) location of nodule deposits of potential commercial interest, (ii) preliminary surveys to delineate extent of the deposit, (iii) evaluation surveys to confirm the deposit as an ore body, and (iv) detail surveys to develop mining plans for ore acquisition. (3) It is principally the last two efforts that must be given serious consideration before one can have sufficient confidence in a cost-benefit analysis of phosphorite mining. On the basis of the samples and information obtained about the phosphorites, one can build a benefication pilot plant. This would then determine what quality phosphate rock would be produced from southern California phosphorites.

Although Global Marine spent about three weeks sampling the Forty Mile Bank deposit, it is doubtful that the type of effort described above can be completed in less than two to three months. Here it is assumed that 90 and 135 days will be required for the 250 TPH and the 1000 TPH operations, respectively, at a daily cost of $4000. The exploration program, therefore, will cost $360,000 for the 250 TPH rate of production and $540,000 for the 1000 TPH rate of production. The other capital requirements classified as depreciable capital are associated with dredging, unloading, crushing/calcining/storage and working capital/ contingency reserve. Table 42 shows that total depreciable capital for the 250 TPH operation yields capital costs of $27.40/$28.07 million and $21.06/$21.72 million for technologies I and II, respectively. For the higher rate of production, 1000 TPH, these depreciable capital costs become $78.42/$79.30 million and $72.52/$73.40 million. When non-depreciable capital, in the form of land, is added to depreciable capital, one obtains total capital requirements associated with an offshore phosphorite mining project (based on assumptions postulated throughout this study).

Table 43 presents a summary of total operating costs per ton. The first four cost classifications have been discussed in more detail in earlier chapters. When these operating costs are added to those of taxes and insurance and administrative expenses, the result is total operating costs. For the 250 TPH operation, total operating costs per ton are \$16.10/\$16.17 and \$8.62/\$8.68 for technology I and II, respectively. The higher rate of production yields operating costs per ton of \$12.80/\$12.76 and \$6.82/\$6.73 for technology I and II, respectively. As expected, the operating costs are significantly lower for the higher rate of production. On the other hand, total capital costs are significantly higher for this production level and only the internal rate of return calculations, presented in the next section, can indicate which will be more profitable to the phosphorite miner.

8.3 Internal Rates of Return

Table 44 presents the derivation of cash flow which is a principal component in the internal rate of return calculations. (4) Total capital requirements were presented in Table 42 and the internal rate of return (IRR) can be calculated. As stated earlier, this represents the discount rate which equalizes the present value stream of net revenue and capital investment. The estimated IRR must then be seen in relation to those of comparable investments (i.e., investments with comparable risk). Alternatively, the problem of risk can be handled as suggested in Section 8.5.

Table 45 presents each of the main components necessary for calculating internal rates of return, as well as the resulting rates. As expected, the rates are considerably higher for the higher rates of production. For the 250 TPH rate of production, the internal rates of return are 7.79/7.4 per cent and 30.13/29.24 per cent for technology I and II, respectively. The high rates for technology II are not unexpected in view of the derived low dredging cost per ton. It must be stressed that this

TABLE 42: CAPITAL COSTS; MILLIONS OF DOLLARS

	Technology I				Technology II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
I. Depreciable Capital								
A. Dredging	7.50		9.0		1.73		3.64	
B. Unloading	0.75	1.35	1.00	1.80	0.75	1.35	1.00	1.80
C. Crushing, Calcining, Storage	16.30		60.75		16.30		60.75	
D. Exploration Costs	0.36	0.36	0.54	0.54	0.36	0.36	0.54	0.54
E. Working Capital and Contingency Reserve*	2.49	2.56	7.13	7.21	1.92	1.98	6.59	6.67
TOTAL**	27.40	28.07	78.42	79.30	21.06	21.72	72.52	73.40
II. Nondepreciable Capital								
(i.e. Land)	2.61	2.61	3.92	3.92	2.61	2.61	3.92	3.92
TOTAL CAPITAL	30.01	30.68	82.34	83.22	23.67	24.33	76.44	77.32

* Calculated at 10 per cent of the sum of dredging, unloading, crushing and calcining and exploration costs.

** Required in Table 45 for calculating Internal Rate of Return.

	Technology I				Technology II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
A. Dredging	7.50		6.00		1.33		0.67	
B. Barge Transport	1.00		0.84		1.00		0.84	
C. Unloading	0.23	0.22	0.21	0.14	0.23	0.22	0.21	0.14
D. Crushing & Calcining, etc.								
1. Labor & Power	1.00		0.77		1.00		0.77	
2. Depreciation	1.09		1.01		1.09		1.01	
3. Maintenance & Repairs	0.82		0.76		0.82		0.76	
E. Taxes & Insurance*	3.00	3.07	2.05	2.08	2.37	2.43	1.94	1.93
Subtotal	14.64	14.70	11.64	11.60	7.84	7.89	6.20	6.12
F. Administrative**	1.46	1.47	1.16	1.16	0.78	0.79	0.62	0.61
TOTAL OPERATING COST	16.10	16.17	12.80	12.76	8.62	8.68	6.82	6.73

* 7.5 per cent of total capital.

** 10 per cent of subtotal.

innovative technology has not been tested (as far as is known) under actual mining conditions. The analysis does not attempt to determine the technological and economic viability of this particular dredging system, which requires additional research. Some tools are developed in Section 8.5, however, which can be used to this end. If alternative outcomes of using this dredging system can be associated with certain probabilities, then the analysis of Section 8.5 can be utilized. The internal rates of return for the 250 TPH operation of technology I appear unattractive even before risk is evaluated. For the 1000 TPH rate of production the resulting rates are more attractive. Still, the high degree of risk associated with this type of investment is unlikely to make technology I attractive under the present assumptions. Without considering the social rates of return, therefore, the tentative conclusion is that technology I will not yield sufficiently high returns on the basis of the assumptions made in this study. The IRR's of technology II appear attractive, but its very recent development and the lack of test data under actual mining conditions increase its riskiness. These rates, therefore, must be analyzed within the context of Section 8.5.

8.4 Sensitivity Analysis

The reader may easily evaluate the sensitivity of the results presented to some of the assumptions underlying the analysis. Any one of these assumptions can be modified and new internal rates of return calculated. Here a few examples are presented in Tables 46 through 52. Table 46 shows the cash flow when the price of phosphate rock is raised by 10 per cent *ceteris paribus*. Table 47 shows how the internal rates

	Technology I				Technology II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor.	Suction	Conveyor
A. Gross Revenue	18.75	18.75	69.00	69.00	18.75	18.75	69.00	69.00
B. Operating Cost	16.10	16.17	51.20	51.04	8.62	8.68	27.28	26.92
C. Net Revenue Before Taxes	2.65	2.58	17.80	17.96	10.13	10.07	41.72	42.08
D. Taxes	1.33	1.29	8.90	8.98	5.07	5.04	20.86	21.04
E. Net Revenue After Taxes	1.33	1.29	8.90	8.98	5.07	5.04	20.86	21.04
F. Depreciation	1.83	1.87	5.23	5.29	1.40	1.45	4.83	4.89
G. Annual Cash Flow (15 yrs)*	3.16	3.16	14.13	14.27	6.47	6.49	25.69	25.93

* Required in Table 5 for calculating the Internal Rate of Return.

TABLE 45: INTERNAL RATES OF RETURN* (Capital and Cash Flow Shown in Millions of Dollars)

	Technology I				Technology II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
1. Total Depreciable Capital	27.40	28.07	78.42	79.30	21.06	21.72	72.52	73.40
2. Annual Cash Flow*	3.16	3.16	14.13	14.27	6.47	6.49	25.69	25.93
3. Internal Rate of Return	7.79	7.40	16.10	16.07	30.13	29.24	35.03	34.93

* For each of 15 years.

of return are affected by this change. For technology I the IRR's rise from 7.79, 7.40, 16.10 and 16.07 per cent to 14.62, 14.13, 21.17 and 21.09 per cent. For technology II the respective changes are from 30.13, 29.24, 35.03, and 34.93 to 34.83, 33.77, 39.94 and 39.78 per cent.

A change in the dilution ratio discussed in Section 5.2 can also be analyzed through a price change as described above. A decrease in the percentage of debris dredged will result in lower operating costs and higher revenue due to higher production. But a price change can be found that can serve as a "proxy" for these higher costs and revenue figures, and thus the effect on the internal rate of return can be found.

Industry sources that have reviewed the cost data in this study feel that the capital investment figures for beneficiation might be on the low side. For this reason Tables 48 and 49 analyze the case where depreciable capital is 10 per cent higher. The first table presents the new cash flow figures and the second table shows how the internal rates of return are affected. For reference to the "base case," these results should be compared to the IRR's in Table 45.

8.4.1 Leasing Policies

Government leasing policies for offshore non-fuel mineral resources are currently being re-examined. It is clear that the resulting leasing policies will be of great importance to any potential phosphorite mines. An exhaustive analysis of optimal federal leasing policies cannot be presented in this study. A brief discussion of royalty requirements and bonus bidding is undertaken, however, since these are the most commonly used means of extracting resource rent. The discussion also indicates how the effects of royalty vs.

TABLE 46: ANNUAL CASH FLOW AFTER 10 PER CENT INCREASE IN POSTULATED PHOSPHATE ROCK PRICE: MILLIONS OF DOLLARS

	Technology I				Technology II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
A. Gross Revenue	20.63	20.63	75.92	75.92	20.63	20.63	75.92	75.92
B. Operating Costs	16.10	16.17	51.20	51.04	8.62	8.68	27.28	26.92
C. Net Revenue Before Taxes	4.53	4.46	24.72	24.88	12.01	11.95	48.64	49.00
D. Taxes	2.77	2.73	12.36	12.44	6.02	5.98	24.32	24.50
E. Net Revenue After Taxes	2.77	2.73	12.36	12.44	6.02	5.98	24.32	24.50
F. Depreciation	1.83	1.87	5.23	5.29	1.40	1.45	4.83	4.89
G. Annual Cash Flow	4.60	4.60	17.59	17.73	7.42	7.43	29.15	29.39

TABLE 47: INTERNAL RATES OF RETURN WITH 10 PER CENT HIGHER PHOSPHATE ROCK PRICES

	Technology I				Technology II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
1. Total Depreciable Capital	27.40	28.07	78.42	79.30	21.06	21.72	72.52	73.40
2. Annual Cash Flow*	4.60	4.60	17.59	17.73	7.42	7.43	29.15	29.39
3. Internal Rate of Return	14.62	14.13	21.17	21.09	34.83	33.77	39.94	39.78

* For each of 15 years.

TABLE 48: ANNUAL CASH FLOW AFTER 10 PER CENT INCREASE IN DEPRECIABLE CAPITAL

	Technology I				Technology II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
A. Gross Revenue	18.75	18.75	69.00	69.00	18.75	18.75	69.00	69.00
B. Operating Cost*	16.28	16.36	51.72	51.57	8.77	8.82	27.77	27.41
C. Net Revenue Before Taxes	2.47	2.39	17.28	17.43	9.98	9.93	41.23	41.59
D. Taxes	1.24	1.20	8.64	8.72	4.99	4.97	20.62	20.80
E. Net Revenue After Taxes	1.24	1.20	8.64	8.72	4.99	4.97	20.62	20.80
F. Depreciation	2.01	2.06	5.75	5.82	1.55	1.59	5.32	5.39
G. Annual Cash Flow	3.25	3.26	14.39	14.54	6.54	6.56	25.94	26.19

*Old Operating Cost + (New Depreciation - Old Depreciation) = New Operating Cost.

TABLE 49: INTERNAL RATES OF RETURN WHEN DEPRECIABLE CAPITAL IS 10 PER CENT HIGHER

	Technology I				Technology II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
1. New Depreciable Capital	30.14	30.88	86.26	87.23	23.17	23.89	79.77	80.74
2. New Annual Cash Flow	3.25	3.26	14.39	14.54	6.54	6.56	25.94	26.19
3. Internal Rates of Return	6.76	6.74	14.49	14.47	27.49	26.67	32.01	31.93

bonus bidding will affect the phosphorite miner in the framework of analysis above.

A royalty requirement has the effect of raising the marginal cost of operation to the phosphorite miner. The cost increment is generally specified as a percentage of the value of the resource at the point of extraction. This is an operating cost, since it is only incurred when production takes place. A graphical exposition of the effect of royalty requirements is presented in Fig. 7. Here one can see the incremental cost curve (IC_1) with positive slope (i.e., as output over time increases the cost of the last unit increases) and a constant incremental revenue curve (IR). Production is expected to continue until IC equals IR, so that with IC output over time becomes Q_1. If a royalty is imposed, the IC_1 (see Fig. 7) curve is shifted upward (reflecting a higher incremental cost at each output level) to IC_2. The point of intersection with IR is now such that Q_2 is the desired output over time. The effect of a royalty requirement, therefore, is to reduce the rate of production from the optimal point of Q_1 to the non-optimal point of Q_2. The latter is non-optimal because the royalty charge is not a social cost; it is a transfer payment by which economic rent is captured by government.

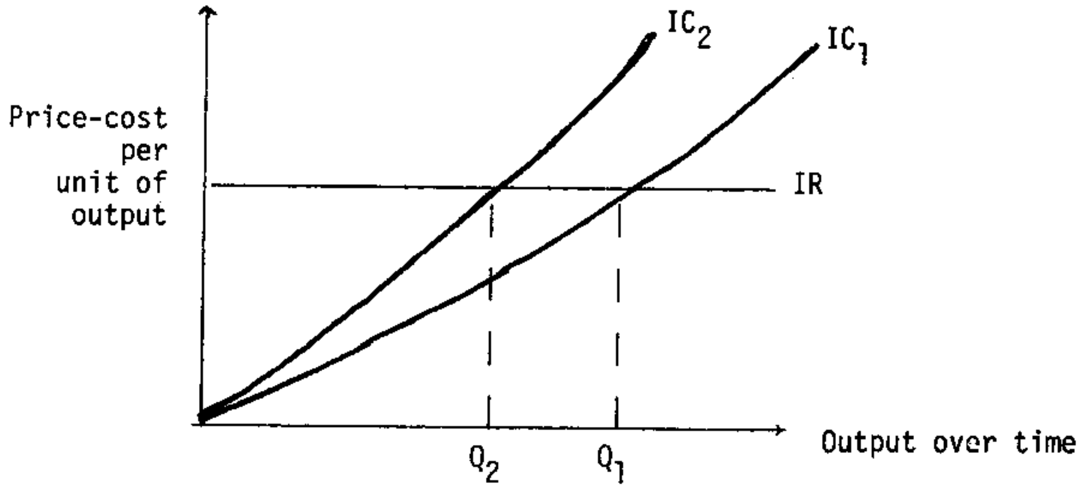


Fig. 7. Effect of Royalty on the Rate of Production

An example of a 10 per cent royalty requirement is presented in Tables 50 through 52. New operating costs and annual cash flows are calculated before the internal rates of return can be derived. Two cases are presented: The royalty is based 1) on the "old operating cost" and 2) on the sales price of phosphate rock minus transportation cost from mining site to onshore processing plant. Since the operating costs before royalty for the 1000 TPH operation for technology II were quite low, there is a significant difference between case (1) and case (2) in Table 52. These results must again be compared to the "base case" in Table 45. The decreases in IRR's due to the royalty imposition are quite obvious. If the old IRR's were low (as was indicated due to the considerable risks involved), it follows that commercial exploitation is even more unlikely when a royalty is imposed.

Given the modest degree of profitability which has been estimated, an optimal federal leasing policy should avoid any royalty requirements and concentrate instead on competitive bonus bidding. By rejecting a royalty charge, the imposition of an additional unit cost on phosphorite production would be avoided. Bonus bidding would serve two functions: 1) competitive bidding would determine who is to receive a lease, and 2) the bonus payment would capture economic rent on behalf of the public. The size of the bonus bid will, therefore, reflect the expected profits of the bidders in undertaking phosphorite mining. If low profits are expected, a royalty charge could effectively prevent mining. Bonus bidding would merely result in a reduced bonus bid, leaving the operator with his own calculated sufficient incentive to proceed with an investment in, and operation of, a plant. It must be added that the above discussion has assumed competition to prevail, but if this is not the case a more complex analysis is required to determine optimal leasing policies.

8.5 Risk Analysis in Economic Evaluation

At various points throughout this study the lack of available information concerning different aspects of a phosphorite mining project has been stated. A brief comment on some of these aspects follows. Thereafter, a procedure for integrating risk (5) into our analysis is presented.

(*i*) Deposit Uncertainties

Considerable attention has been given to the problem of insufficient sampling. Although the assumption has been made that a considerable exploration program will be undertaken prior to commercial exploitation, a large degree of uncertainty is associated with what will be found, how successfully the deposits can be delineated, etc.

TABLE 50: OPERATING COSTS WITH ROYALTY PAYMENTS; DOLLARS PER TON

		Technology I				Technology II			
		250 TPH		1000 TPH		250 TPH		1000 TPH	
		Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
1. Operating Costs Before Royalty Payments*		16.10	16.17	12.80	12.76	8.62	8.68	6.82	6.73
2. Royalty Payments**	(1)	1.61	1.62	1.28	1.28	0.86	0.87	0.68	0.67
	(2)	1.78	1.78	1.64	1.64	1.78	1.78	1.64	1.64
3. Operating Costs Including Royalty Charges	(1)	17.71	17.79	14.08	14.04	9.48	9.55	7.50	7.40
	(2)	17.88	17.95	14.44	14.40	10.40	10.46	8.46	8.37

* See Table 43.

** Royalty payments are generally calculated on the basis of 'well-head' or 'mining-site' value. This would be sales price minus transportation costs (assuming no beneficiation is undertaken). Two cases are presented: (1) "Operating costs before royalty payments" are used as an approximate basis for calculating royalty payments, and (2) "Sales price minus transportation cost" is used; in either case 10 per cent of the base is used. Note that prices per ton of phosphate rock used are $18.75 for a 250 TPH operation and $17.25 for a 1000 TPH rate of production and Table 43 specifies transportation costs.

TABLE 51: ANNUAL CASH FLOW WITH 10 PER CENT ROYALTY; MILLIONS OF DOLLARS

		Technology I				Technology II			
		250 TPH		1000 TPH		250 TPH		1000 TPH	
		Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
A. Gross Revenue		18.75	18.75	69.00	69.00	18.75	18.75	69.00	69.00
B. Operating Costs	(1)*	17.71	17.79	56.32	56.16	9.48	9.55	30.00	29.60
	(2)**	17.88	17.95	57.76	57.60	10.40	10.46	33.84	33.48
C. Net Revenue Before Taxes	(1)	1.04	0.96	11.68	12.84	9.27	9.20	39.00	39.40
	(2)	0.87	0.80	11.24	11.40	8.35	8.29	35.16	35.52
D. Taxes and Net Revenue After Taxes*	(1)	0.52	0.48	5.84	6.42	4.64	4.60	19.50	19.70
	(2)	0.44	0.40	5.62	5.57	4.18	4.15	17.58	17.76
F. Depreciation		1.83	1.87	5.23	5.29	1.40	1.45	4.83	4.89
G. Annual Cash Flow	(1)	2.35	2.35	11.07	11.71	6.04	6.05	24.33	24.59
	(2)	2.27	2.27	10.85	10.86	5.58	5.60	22.41	22.65

* and **, See notes in Table 50.

TABLE 52: INTERNAL RATES OF RETURN WITH RESOURCE COST, I.E., ROYALTY AT 10 PER CENT

	Technology I				Technology II			
	250 TPH		1000 TPH		250 TPH		1000 TPH	
	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor	Suction	Conveyor
1. Total Depreciable Capital	27.40	28.07	78.42	79.30	21.06	21.72	72.52	73.40
2. Annual Cash Flow (1)*	2.35	2.35	10.85	11.75	6.04	6.05	24.33	24.59
(2)**	2.27	2.27	11.07	10.86	5.58	5.60	22.41	22.65
3. Internal Rates of Return (1)	3.33	2.99	11.29	12.17	27.97	27.09	33.09	33.04
(2)	2.85	2.52	10.91	10.72	25.63	24.86	30.32	30.27

* and **, See notes in Table 50.

(*ii*) Chemical and Mineralogical Composition of Phosphorites

In large parts of Chapter 5 the available samples and their chemical and mineralogical composition have been evaluated. Phosphate produced from these nodules might not be able to meet the desired specifications. Apparently, this could be a significant problem. Relative to certain minerals and chemicals, the consequences of not meeting specifications are severe. (6) Only extremely high processing costs could eliminate these problems.

(*iii*) Mining Technologies

This study has presented two technologies that have been suggested to us by industry sources. It appears that less uncertainty is associated with technology I than with technology II. The basic lifting mechanism of submerged dredge pumps is well documented, but this is not so for the more recent innovations associated with technology II. Both technologies need to be tested in pilot operations, however, before one can have confidence in them. Also, such pilot operations would provide a check on theoretical cost calculations.

(*iv*) Beneficiation

Again, no pilot plants for phosphorites have been in operation to test the technological and economic feasibility of their beneficiation. It is likely that less uncertainty is associated with the technology of such operations than with respect to the three subsections above.

(*v*) Market Considerations

Substantial fluctuations in market demand for phosphate rock are neither new nor unique to this particular product. Still, large fluctuations in prices and quantities demanded generated by a large number of different causes, could easily affect the decisions of company managers. Their behavior, as opposed to that of the stockholders, will be discussed below in relation to the handling of risk.

(*vi*) Regulations

Some aspects of regulation have already been considered briefly in earlier chapters. Federal, state and local regulation must be taken into account in a more detailed feasibility study. The increasingly important role of environmental impact statements supports this conclusion. Given the changing nature of such rules and regulations, in addition to the frequent arbitrariness of bureaucratic decision-making, a large degree of uncertainty is associated with these aspects of investment analysis. A suggested procedure for integrating risk and uncertainty into our analysis is presented below.

8.5.1 Model of Risk Analysis

This model can be used to integrate all of the uncertainties discussed into the economic evaluation. To simplify the heuristic analysis below, the following assumptions are made:

(*i*) Only two events (z and y) can take place. [For instance, the event z gives the internal rate of return (IRR) resulting when high-quality phosphorites are found, say with the level of P_2O_5 greater or equal to 30 per cent. The other event y denotes the IRR yielded when the phosphorites contain less than 30 per cent P_2O_5.] (7)

(*ii*) The probability of either event taking place is known. The probability of obtaining event z is given as x [i.e., $P(z) = x$] and the probability of obtaining event y is given as (1-x)[i.e., $P(y) = 1-x$]. The latter follows from the requirement that

$P(z) + P(y) = 1$ or, $P(y) = 1-P(z)$.

(*iii*) The desired IRR (i.e., the competitive rate of return if competition is assumed) is known. Call this R.

The question that needs to be answered is this: what is the minimum probability of the favorable event z gaining acceptance to achieve the desired internal rate of return equal to R? The equation to be solved is:

$$R = z \cdot P(z) + y \cdot P(y)$$

$$\text{or } R = z \cdot x + y \cdot (1-x)$$

If $R = 0.15$ (or 15%), $z = 0.25$ and $y = 0.01$ then

$$0.15 = (0.25) \cdot x + (0.01) \cdot (1-x)$$

$$\text{or } x = \frac{0.14}{0.24} = \underline{0.58}$$

The assumptions were that IRR = 25 per cent in the favorable event, IRR = 1 per cent in the unfavorable event and the minimum desired IRR is 15 per cent. Then, one should not proceed with the project if circumstances indicate a probability of the favorable event less than 58 per cent. If the assumptions are changed so that the IRR in the unfavorable event is minus 15 percent, then:

$$0.15=(0.25)\cdot x+(-0.15)(1-x)$$

$$x = \frac{0.30}{0.40} = \underline{0.75}$$

This shows that when the unfavorable event has more serious consequences (losing 15 per cent now vs. gaining 1 percent in the previous case), one requires a higher probability of favorable outcome (i.e., not less than 75 per cent).

The analysis above also assumes risk neutrality. This is frequently postulated in economic theory. It implies that the decision-maker maximizes expected value. Alternatively, he is indifferent to having between $1 for certain, and a given lottery ticket. This ticket has, for example, a 75 per cent probability of losing $20 and a 25 per cent probability of winning $64. This result follows from the fact that:

$$\$1 = (0.75) \cdot (\$-20) + (1-0.75) \cdot (\$64)$$

The postulate of risk neutrality is generally accepted in portfolio analysis if one assumes that the investor has an optimum or "efficient portfolio." This type of portfolio has no large part of total investments allocated to any one stock. Rather, they are spread among a large number of stocks. This is frequently true for many investors, and risk neutrality is then an acceptable postulate. If the stockholders are risk-takers (i.e., gamblers or "plungers") or if they are risk-averse (i.e., willing to pay a premium to avoid risk), however, then risk associated with investments must be analyzed differently. If a company president (manager or any other decision-maker with whom the analysis is concerned) has a different criterion than that of the stockholders, one might well observe risk-averse behavior. The severe consequences of losses incurred (like being fired, for example) are an important reason why this is the case. In the model above it is assumed that the companies evaluating phosphorite mining are owned by a large number of stockholders, who have well-balanced portfolios with only a small part of their stock in any one company. Also, the managers of the companies have the same criterion as that of the stockholders (i.e., to maximize expected profits).

If one believes that the decision-makers are risk-averse rather than risk-neutral, the following simple procedure can be followed. An attempt may be made to estimate the percentage of the planned investment one is willing to pay to eliminate the undesirable risk-- the so-called "risk premium." When the IRR has been calculated, this risk premium is subtracted from it and the resulting IRR evaluated in light of comparable investments. Depending upon the assumptions made about the behavior of the decision-maker, different approaches can be taken toward risk analysis. If risk-averse behavior is postulated, one can assess the internal rates of return in Sections 8.3 and 8.4 and determine whether these allow for a sufficiently large risk premium and still yield returns competitive with comparable investments. If a comparable investment yields 20 per cent for example, and the internal rate of return in the phosphorite project is 30 per cent, a maximum risk premium of 10 per cent is allowed.

8.6 Social Rate of Return

Up to this point only the private rate of return has been considered, though references have been made throughout to potential social effects. In economic analysis, attention must be paid to benefits and costs generated by an investment project but not fully captured or internalized by the firm in question. These external costs and benefits are generally called "externalities." A considerable theoretical literature has been generated in recent years in economics on this particular topic. This study will not go into much detail about this issue, but the reader may consult the companion report on offshore sand and gravel mining for an additional discussion of externalities. The important point is the extent to which either external costs or external benefits are unequal. In this case the private internal rate of return must be modified to account for such external effects.

8.6.1 External Benefits

The two main categories of potential external benefits in these considerations are: (1) social benefits generated by the development of new technologies, (8); and (2) the generation of employment and income in areas affected by the phosphorite mining project. Since dredging technology I would apply existing technology and mainly put it to new use, it is unlikely that significant benefits will be generated by this dredging system. Technology II would be more likely to give external benefits of various kinds. As pointed out in the report by Kiss, the technological innovations employed in the dredging system could find applications in many other fields. Steam or gas, instead of water, under pressure could then be used as a force of propulsion.

In beneficiation, knowledge might be gained about upgrading and beneficiation of phosphorite nodules. It is most likely, however, that these breakthroughs can be fully captured by the firm (through patents, etc.) so that little significant external benefit is generated. Only in the case where the firm cannot capture the full social value of its innovations will external benefits be generated. This also holds for the dredging technology argument, so that neither development may cause much social benefit external to the firm. And since external benefits associated with point (2) above are likely to be small, one might be justified in concluding that no significant social benefits will be generated by a phosphorite mining project.

8.6.2 External Costs

Indications are that these could be significant. The major problem areas are: (1) effects of ocean mining on the physical, chemical, and biological environment at the dredging site, (2) effects on marine environment from barge and tug traffic, (3) possible water pollution if hydraulic unloading is utilized, and (4) dust and noise problems associated with the beneficiation plant and the shipment of phosphate rock. It must be stressed that these are potential problem areas. Most, if not all, can possibly be prevented if sufficient incentives exist. Where, for instance, rules and regulations are lax so that a firm can impose external costs on society and not incur costs for doing so, socially adverse behavior might be expected. Economic theory shows how socially optimum adjustments may occur under free market conditions when (1) individuals affected have complete knowledge of what is happening, (2) property rights are well defined, and (3) transaction costs are insignificant (i.e., the numerous individuals affected by the company's behavior can join forces and negotiate with the company at small or insignificant cost). Often these conditions are not met, however, and a social optimum is not achieved.

It is most likely that current air pollution and noise pollution laws are sufficiently strict so that a phosphorite mining project will not impose significant social costs. In fact, many claim that laws regulating such activities are now so strict that social costs are incurred by preventing those economic activities that would have a significant positive social return. Most of the concern about phosphorite mining will be concentrated, however, on the effects of dredging on the ocean environment. Any method of dredging will cause suspension of sediments in the water column and much research is presently under way to determine its effects on the marine environment. One consequence of water discharge during dredging is to increase the content of dissolved nutrients (phosphates,nitrates, silicates, etc.) in the water column. (9) But the overall effects are not certain and will vary according to the given marine environment at hand. What is required is a study of the marine environment at the potential dredge sites. A small pilot operation would most likely be needed as well for any such complete base-line study. It seems clear that a test of the technological viability of the dredging system could be combined with a study of the impact of phosphorite mining on the marine environment. Since such studies require observations over an extended period, any company with commercial mining plans for phosphorites must initiate such environmental research several years prior to the intended start of mining.

This brief discussion indicates that social costs might outweigh social benefits associated with marine phosphorite mining. One should, however, include considerations of possible social costs associated with onshore phosphate mining that might be avoided if offshore phosphorite mining displaces onshore operations. If the quality of marine phosphorites is good, and as the quality of onshore ores declines, such replacement is possible. It is, therefore, difficult to determine whether social costs or social benefits will dominate. Given the present state of knowledge, one might well be justified in concluding that social benefits approximately offset the social costs. Thus the social rate of return would not be different from the private rate of return.

8.7 Conclusion

Of necessity, this study has ignored many factors that should be included in a definitive economic evaluation of a marine phosphorite mining project. An attempt has been made, however, to concentrate on the major factors and to evaluate them to the extent allowed by available information. Unfortunately, much information is unavailable, making an exhaustive analysis impossible. An attempt has also been made to point out the areas most in need of better information and it is hoped that this will be of help to subsequent researchers.

No definitive conclusions are provided here regarding the profitability of offshore phosphorite mining. Various alternative technological combinations have been presented with their corresponding internal rates of return. This has been done for the purpose of (1) indicating how different technological specifications affect the overall profitability and (2) allowing the reader to select that technological combination (and the associated IRR's) which he finds most appropriate. Likewise, the sensitivity of our results has been analyzed with respect to (a) phosphate rock price changes, (b) changes in required investment and (c) alternative leasing policies. This study has tried to present the analysis in such a way that the reader can undertake further sensitivity analysis for factors which he considers important.

If any tentative conclusions is to be made they must be influenced by the high degree of risk, and/or uncertainty, associated with an investment of this kind. The internal rates of return that have been calculated were invariably low for technology I, especially when risk of deposit and phosphorite characteristics, beneficiation, etc., are taken into account. Technology II yielded considerably higher internal rates of return, as expected, but considerable risk is associated with its application to offshore phosphorite mining. Only by specifying the extent of these risks can a more definite conclusion be made, and much additional research is required to accomplish this.

If a tentative conclusion must be made, however, it is clear that technology II (jet lift dredge) appears most promising. This requires a total estimated capital investment of $23.67/$24.33 million for a 250 TPH operation and $76.44/$77.32 million for a 1000 TPH operation*, and yields internal rates of return of 30.13/29.24 per cent and 35.03/34.93 per cent for the 250 TPH and the 1000 TPH operation, respectively. Again, however, one must stress the high degree of risk and uncertainty associated with this innovative technology which is based on a jet lift dredging process. Pilot operations under actual dredging conditions are required to verify its technical and economic viability.

*Depending on type of unloading technology. This cost is inclusive of land. See Table 42 for details.

References and Footnotes to Chapter 8.

(1) One could easily argue for a different time profile of investment expenditures. The assumption made is not particularly unrealistic, however; since it facilitates our calculations, it is seen as a useful approximation.

(2) Personal communication from San Francisco shipping agent, July, 1976. The example is based on 1) a 30-40,000 ton bulk carrier, and 2) no return cargo in either case.

(3) Kaufman, Raymond and William Siapno, "Future Needs of Deep Ocean Mineral Exploration," Deep-Sea Ventures, Inc., Offshore Technology Conference Paper No. 1543, p. 2.

(4) Let annual cash flow, the difference between all capital expenditures, E (assumed to take place in the first year), and land, L, be denoted C.F. and X, respectively. Then

$$E = \sum_{j=1}^{N} \frac{C.F.}{(1+i)^j} + \frac{L(1+i)^N}{(1+i)^N}$$

$$\text{or } X = E - L = \sum_{j=1}^{N} \frac{C.F.}{(1+i)^j}$$

Manipulating mathematically, we derive

$$\frac{X}{C.F.} = \left[\frac{1 - \frac{1}{(1+i)^N}}{i} \right]$$

(5) The terms "risk" and "uncertainty" are commonly differentiated by economists. The former is used when one can assign a given probability or chance to a given event. Uncertainty is used when this cannot be done. This analysis is concerned exclusively with risk so that quantitative analysis can be employed.

References and Footnotes to Chapter 8 (continued)

Uncertainty associated with an investment makes the investment even more unattractive and the type of quantititive risk analysis presented here cannot be employed. Also, since one cannot associate probabilities with alternative outcomes, it would be impossible to insure against unfavorable events.

(6) Personal communication from representative of TVA, July 20, 1976. The magnesium oxide content in phosphate ores is one example of a severe processing problem. Leaching could be undertaken but this would generally also affect the phosphate content of the ore. Additionally, leaching costs are high.

A mitigating factor in these considerations is the reported deterioration in quality (i.e., grade and impurities) of Florida phosphate rock.

(7) One is clearly not restricted to utilizing only two events z and y, as in our example. Numerous events,- x,y,z, etc. and their estimated probabilities, can be used to derive new "compound" events.

(8) Mead, Walter J., and Philip E. Sorensen, "The Principal External Costs and Benefits of Marine Mineral Recovery," paper No. 1178 presented at the Second Annual Offshore Technology Conference, April, 1970.

(9) Amos, A.F., K. C. Haines, O. A. Roels, and Christopher Garside, "Effects of Surface-discharged Deep Sea Mining Effluent," Marine Technology Journal, July/August, 1972, p. 40.

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